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POWER TECHNOLOGY

OAST Summer Workshop

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Office of Aeronautics and Space Technology and Old Dominion University

NOTICE

The results of the OAST Space Technology Workshop which was held at Madison College, Harrisonburg, Virginia, August 3 - 15, 1975 are contained in the following reports:

EXECUTIVE SUMMARY

VOL I DATA PROCESSING AND TRANSFER

VOL II SENSING AND DATA ACQUISITION

VOL III NAVIGATION, GUIDANCE, AND CONTROL

VOL IV POWER

VOL V PROPULSION

VOL VI STRUCTURE AND DYNAMICS

VOL VII MATERIALS

VOL VIII THERMAL CONTROL

VOL IX ENTRY

VOL X BASIC RESEARCH

VOL XI LIFE SUPPORT

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NASA

Office of Aeronautics and Space Technology

Summer Workshop

August 3 through 16, 1975

Conducted at Madison College, Harrisonburg, Virginia

Final Report

POWER TECHNOLOGY PANEL

Volume IV of XI

OAST Space Technology Workshop

POWER TECHNOLOGY PANEL

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TABLE OF CONTENTS

SUMMARY

Within the guidelines proposed by OAST, the Power Working Group (PWG) established the objectives of identifying the technology requirements for three basic areas of space technology: Shuttle Payloads, Mission Driven Technology, and Opportunity Driven Technology. Each of these three areas was further subdivided and considered according to the following outline: (I) Energy Sources and Conversion (A. Solar Photovoltaics, B. Solar and Nuclear Thermal Electric, C. Chemical Conversion, D. Ambient Field Trapping), (II) Power Processing, Distribution, Conversion and Transmission, and (III) Storage. Various technology areas have been suggested for OAST consideration. These are compilation of inputs from various sources and have been discussed in detail in the report. The main conclusions reached by the PWG are as follows: (1) power system technology currently available is adequate to accomplish all missions in the 1973 Mission Model, (2) Improved Power Systems technology can provide significant benefits in operational capabilities and costs, even for the 1973 Mission Model (sixteen such areas have been identified), (3) major advancements in Power Systems technology must be made if the Outlook for Space and other advanced user plans are to be accomplished.

INTRODUCTION

This is the final report of the Power Working Group assembled under the auspices of the OAST Space Technology Summer Workshop. The Power Working Group (PWG) met at Madison College, Harrisonburg, Virginia, August 4-15, 1975.

The objective of the Workshop as understood by the PWG was to identify, for the consideration of OAST management, three specific areas of space technology for possible pursuit. The technology areas are listed below, with especial emphasis to be placed on Item 1:

1. Shuttle Payloads--technology experiments which might make use of the capabilities of the Space Transport System.

2. Mission Driven Technology--technology needed to accomplish the missions in the '73 Mission Model, or technology which if suitably developed would offer significant improvements over the level of technology currently in use.

3. Opportunity Driven Technology--technology needed to support potential space opportunities of the future as identified by users.

The technologies listed are compilations of inputs from various sources; they are not a recommended listing nor is any priority to be inferred. Further, they are probably not a comprehensive list. The three technology areas listed above are treated separately in Books I, II, and III.

The approach taken by the PWG took the following chronology:

Assemblage of input materials and data.
Subdivision of power systems into subsystems and assignments of members to each subsystem.
Generation of technology areas by subsystems.
Review of technology areas by entire PWG.
Drawing of conclusions.
Preparation of presentation to management and final report.

Inputs were obtained from a number of sources. Most of them are listed in Appendix A.

AREAS OF CONSIDERATION

Each of the three main areas, i.e., Shuttle Payloads, Mission Driven Technology, and Opportunity Driven Technology were further subdivided and considered according to the detailed outline of Appendix B and abbreviated below for reader convenience:

I. Energy Sources and Conversion

A. Solar Photovoltaics
B. Solar and Nuclear Thermal Electric
C. Chemical Conversion
D. Ambient Field Trapping

II. Power Processing, Distribution, Conversion and Transmission

III. Storage

See Figure 1 for a pictorial of this subdivision.

Please note that this outline is a "first cut best judgement." Consequently, a detailed review of Appendix B might reveal other technology areas quite worthy of OAST pursuit. Because they were outside of this outline, however, they were not considered by the PWG.

Titles of the technology areas submitted for OAST consideration are listed in the next section with detailed summaries and submittals contained in Books I, II, and III.

TECHNOLOGY AREA TITLES

Shuttle Payloads (Book I)

I. Energy Sources & Conversion

A. Solar Photovaltaic

1. Deployment, Retraction and Dynamics of Lightweight Structures for Solar Cell Arrays

2. Demonstration of High Voltage Solar Cell Array and High Voltage Power Management for SEPS

3. SSPS Technology Testing and Demonstration Experiments

4. Measurement of Solar Radiation Intensity and Spectral Distribution

5. Environmental Tests of Advanced Solar Cells

6. Environmental Tests of Materials for Advanced Solar Arrays

7. Liquid Metal Slip Ring Experiment

8. Extended Environmental Testing ofSolar Array Mechanisms and Materials

9. In Space Assembly of High Power Transfer Devices

10. Environmental Tests of Advanced Solar Cell Modules and Subarrays

B. Solar & Nuclear Thermo Electric

1. Demonstrate Emergency Cooling System in Zero-Gravity for Brayton Isotope Power System

2. Demonstration of Brayton Isotope Power in Pointing Experiment for Large Concentrators

Shuttle Payloads (Book I) Continued

3. Scalable, Free Flying Facility for Testing of High Power Density Components
4. Demonstration of a 500 KWe Solar Brayton Space Power System for Transmitting Electric Power to Earth
5. Demonstration of a 100 KWe Nuclear Space Power System (Brayton-Thermionic) for Electric Power or Propulsion

C. Energy Conversion - Chemical

1. Radio Frequency Mass Quantity Gauging

II. Power Processing, Distribution, Conversion & Transmission

1. Unattended Utility Power Station
2. Sphinx B
3. Sphinx C
4. Flight Demonstration of Power System Components Cooled by Integral Heat Pipes
5. SEPS Prime Propulsion Demonstration

III. Storage

1. Silver-Zinc Cell Experiment
2. High Energy Density Battery Experiment

Mission Driven Technology Requirements (Book II)

I. Energy Sources and Conversion

A. Solar Photovoltaic

1. Solar Cell Array for Electric Propulsion
2. High Efficiency, Low Cost, Radiation Resistant, Light-Weight, Silicon Solar Cells
3. Power Transfer Across Rotating Joints
4. High Temperature, High Efficiency, Radiation Resistant III-V Compound Solar Cells

B. Solar and Thermo Electric

None

C. Chemical Conversion

1. Hydrogen/Oxygen Fuel Cell Module for Tug
2. Radio Frequency Mass Quantity Gauging

II. Power Processing, Distribution, Conversion, & Transmission

1. Spacecraft Charging and High Voltage Interactions with Plasmas
2. Unattended Utility Power Station
3. Automated Power Systems Management
4. Solar Array Power Generation and Management, HVSA
5. Advanced Power Processing/Monitoring System
6. Multi KW, High Voltage Power Processor and Distribution System for Special Applications
7. Self-Aligning Multipin Low/High Voltage Electrical Connector Assembly

Mission Driven Technology Requirements
(Book II) Continued

III. Storage

1. Ni-Cd Secondary Battery System for LST
2. $Ni\text{-}H_2$ Energy Storage System for Low Earth Orbit, Long Life Payloads, LST
3. High Energy Density Batteries

Opportunity Drivers (Book III)

I. Energy Sources and Conversion

A. Solar Photovoltaic

1. Solar cell array for SSPS

2. High Efficiency, Radiation Resistant, High Temperature Lightweight Solar Cells

3. Multijunction, Edge-Illuminated Silicon Solar Cell

4. High Efficiency, Low Cost, Radiation Resistant Electromagnetic Wave Energy Generator (EWEG)

B. Solar and Nuclear Thermo Electric

1. Solar Concentrators for High Temperature Energy Conversion to Electric Power

2. Nuclear Electric Power for Propulsion or Large Power Uses

3. Extra-Terrestrial Brayton Energy Conversion (Solar and Nuclear Heat Sources)

4. Extra-Terrestrial Stirling Energy Conversion (Solar and Nuclear Heat Source)

5. High Performance Thermionic Conversion

6. Solar Dielectric Power Conversion

7. Nuclear Thermoelectric Power System

C. Chemical Conversion

1. Dielectric Film Stack Cryogenic Tank Insulation

2. Advanced Fuel Cell Technology

Opportunity Drivers (Book III) Continued

II. Power Processing, Distribution, Conversion & Transmission

1. Power Processing and Distribution Systems for Gigawatt Class Power Systems
2. High Bus Voltage Power Processor and Distribution System Technology
3. Laser Energy Photovoltaic Converter
4. Ultra High Power Energy Conversion and Transmission System Technology

III. Storage

1. Large Ni-Cd Batteries for Space Station Application
2. Use of Flywheels for Mechanical Storage of Energy

SPACE POWER SYSTEM ELEMENTS

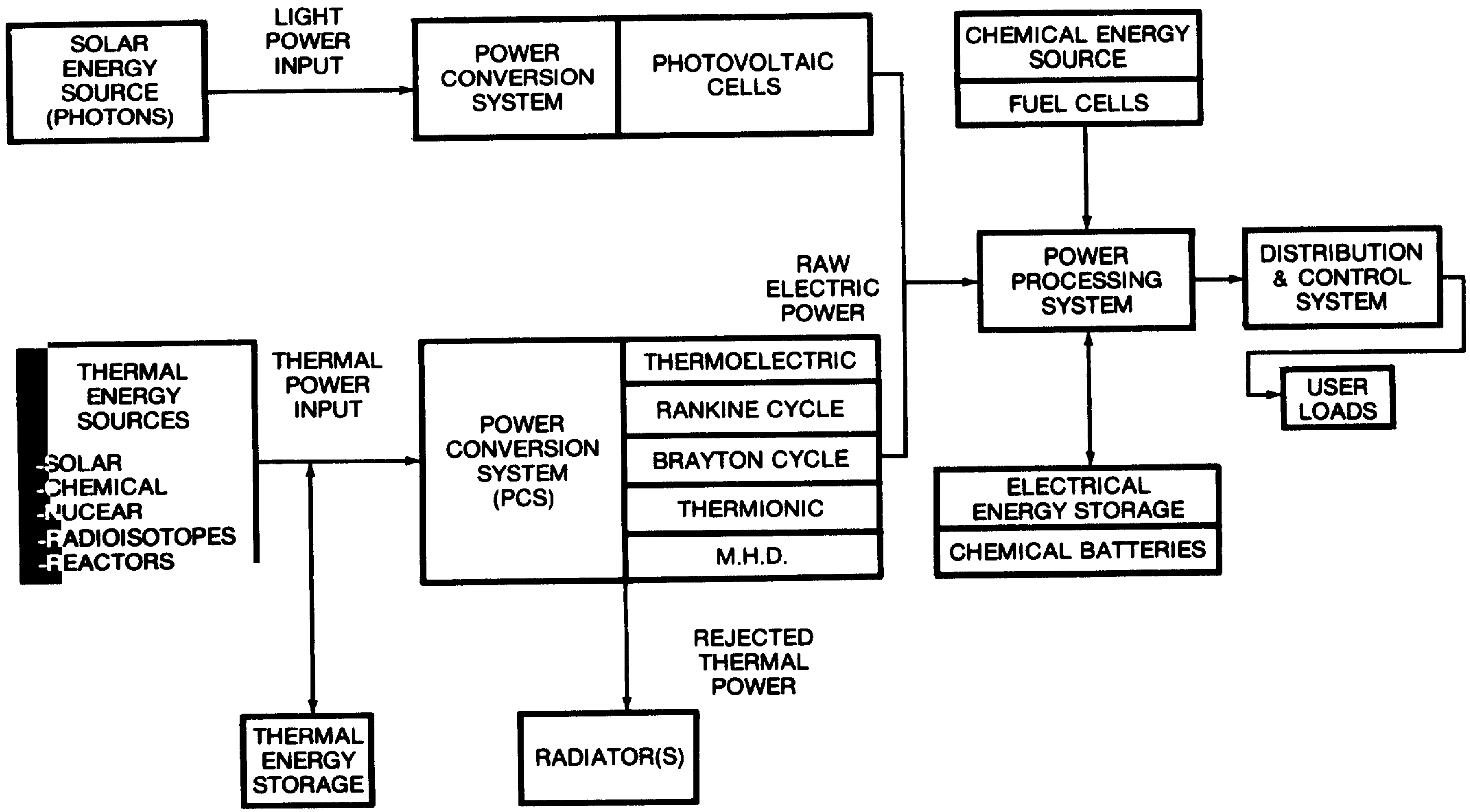

FIG. 1

BOOK I: SHUTTLE PAYLOADS

I. Energy Sources and Conversion

A. Shuttle Experiments Related to Solar Photovoltaic Components and Systems

Two new requirements for improved photovoltaic systems are driving technology in this field. One firm requirement for solar space power systems which provide power for new Solar Electric Propulsion Systems (SEPS), is an 85% weight reduction of photovoltaic systems. The second requirement which is potential in nature, is for low cost, high efficiency, and high temperature solar electric convertors for the Space Satellite Power System (SSPS).

Two experiments directly related to the SEPS are proposed. In one, the dynamics of deployment and retraction of lightweight structures will be studied in a zero-gravity environment to validate designs now being developed for solar cell arrays. The second experiment specifically related to SEPS is to demonstrate, in the space environment, the operation of a lightweight, high voltage solar cell array using switching devices integral with the array for power management.

Four experiments directly related to the SSPS are proposed. One experiment is directed at demonstration of space assembly techniques for ultra-lightweight structures supporting solar cell arrays, and determination of their dynamic characteristics. The other three experiments will demonstrate the space-worthiness of the mechanical integrity of the SSPS array design, the microwave generators, and a full capability but scaled-down SSPS.

Seven additional experiments are proposed related to solar cell calibration and to space synergistic testing of materials, components, and subsystem arrays required in both SEPS as well as all other payloads using photovoltaic arrays. All of these experiments are proposed for both low earth orbit and for geosynchronous orbit under both 1 AU and concentrated sunlight. One experiment is aimed at measuring the intensity and spectral distribution of solar radiation between 0.2 mm to 1.5 mm. The other six experiments test the long term space worthiness of advanced solar cells, materials (covers, encapsulants, flexible substrates, interconnects, anti-reflection coatings, new liquid metal power transfer slip rings, lubricants, conductors, and insolators, and advanced solar cell arrays.

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. ______
PAGE 1

1. REF. NO. 17 **PREP DATE** 8/1/75 **REV DATE** ______ **LTR** ______
CATEGORY Electric Power

2. TITLE Deployment, Retraction and Dynamics of Lightweight Structures for Solar Cell Arrays

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

Determine dynamics of candidate lightweight structures to verify analytical model and provide requirements for attitude control and orientation. Verify deployment and retraction of candidate structures.

4. SCHEDULE REQUIREMENTS **FIRST PAYLOAD FLIGHT DATE** ______
PAYLOAD DEVELOPMENT LEAD TIME ______ **YEARS. TECHNOLOGY NEED DATE** ______

5. BENEFIT OF ADVANCEMENT **NUMBER OF PAYLOADS** ______

TECHNICAL BENEFITS Lightweight structures for solar arrays are needed for SEPS. A zero-g test is needed to validate the designs now being developed. Results will also be used to improve the analytical methods used for predicting array dynamics.

POTENTIAL COST BENEFITS ______

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS ______

REQUIRED SUPPORTING TECHNOLOGIES ______

7. REFERENCE DOCUMENTS/COMMENTS ______

FT (TDR-1) 7/75

TITLE ____________________ NO. ______

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Lightweight solar array structures together with lightweight array blanket. Can be article now being developed in SEP program.

TEST DESCRIPTION: ALT. (max/min) ____ / ____ km, INCL. ____ deg, TIME ____ hr

BENEFIT OF SPACE TEST: ____________________

EQUIPMENT: WEIGHT ____ kg, SIZE ____ X ____ X ____ m, POWER ____ kW

POINTING ____ STABILITY ____ DATA ____

ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION ____ / ____

SPECIAL GROUND FACILITIES: ____________________

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ____

9. GROUND TEST OPTION TEST ARTICLE: ____________________

TEST DESCRIPTION/REQUIREMENTS: ____________________

SPECIAL GROUND FACILITIES: ____________________

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ____________________

TEST CONFIDENCE ____

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION							GROUND TEST OPTION						
								COST ($)							COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ______ (SUM OF PROGRAM COSTS $ ______)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ______

F1 (TDR 2) 7/75

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. ______
PAGE 1

1. REF. NO. 17 **PREP DATE** ______ **REV DATE** ______ **LTR** ______
CATEGORY Electric Power

2. TITLE Demonstration of High Voltage Solar Cell Array and High Voltage Power Management for SEPS.

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

Demonstrate in the space environment the operation of a lightweight high voltage solar cell array using switching devices integral with the array for power management.

4. SCHEDULE REQUIREMENTS **FIRST PAYLOAD FLIGHT DATE** ______
PAYLOAD DEVELOPMENT LEAD TIME ______ **YEARS. TECHNOLOGY NEED DATE** ______

5. BENEFIT OF ADVANCEMENT **NUMBER OF PAYLOADS** ______

TECHNICAL BENEFITS The high voltage array and integral power management offers improved reliability and lower weight for the power systems for SEPS. The validity of this approach must be verified by a test in the total space environment to reduce the risk for later SEPS applications.

POTENTIAL COST BENEFITS ______

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS ______

REQUIRED SUPPORTING TECHNOLOGIES ______

7. REFERENCE DOCUMENTS/COMMENTS ______

FT (TDR-1) 7/75

TITLE ______________________ NO. ______
PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: High voltage solar cell array with integral switches and power management subsystems.

TEST DESCRIPTION: ALT. (max/min) ____/____ km, INCL. ____ deg, TIME ____ hr

BENEFIT OF SPACE TEST: ______

EQUIPMENT: WEIGHT ____ kg, SIZE ____ X ____ X ____ m, POWER ____ kW
POINTING ____ STABILITY ____ DATA ____
ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION ____/____
SPECIAL GROUND FACILITIES: ______
EXISTING: YES ☐ NO ☐
TEST CONFIDENCE ____

9. GROUND TEST OPTION TEST ARTICLE: ______

TEST DESCRIPTION/REQUIREMENTS: ______

SPECIAL GROUND FACILITIES: ______
EXISTING: YES ☐ NO ☐
GROUND TEST LIMITATIONS: ______
TEST CONFIDENCE ____

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ______ (SUM OF PROGRAM COSTS $ ______)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ______

FT (TDR 2) 7/75

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. ______
PAGE 1

1. REF. NO. ______ **PREP DATE** ______ **REV DATE** ______ **LTR** ______
CATEGORY ______

2. TITLE SSPS Technology Testing and Demonstration Experiments

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

(a) Demonstrate space assembly and determine dynamics of ultra-light weight structures for solar cell arrays.
(b) Demonstrate space worthiness of the solar cell array design developed for SSPS.
(c) Demonstrate space worthiness of microwave generators developed for SSPS. The test generators probably will be reduced in size but will generate equivalent power densities as those required for SSPS.
(d) Demonstrate space worthiness of a scaled down version of the SSPS. System operation could be demonstrated in low earth orbit, and system durability tested later in a geosynchronous earth orbit.

4. SCHEDULE REQUIREMENTS **FIRST PAYLOAD FLIGHT DATE** ______
PAYLOAD DEVELOPMENT LEAD TIME ______ **YEARS. TECHNOLOGY NEED DATE** ______

5. BENEFIT OF ADVANCEMENT **NUMBER OF PAYLOADS** ______
TECHNICAL BENEFITS These tests are needed to identify technological deficiencies to be corrected and to eventually make a rational decision on building a full scale SSPS.

POTENTIAL COST BENEFITS ______

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT
TECHNICAL PROBLEMS ______

REQUIRED SUPPORTING TECHNOLOGIES ______

7. REFERENCE DOCUMENTS/COMMENTS ______

FT (TDR-1) 7/75

TITLE ______________________________ NO. ______

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: ______________________________

TEST DESCRIPTION : ALT. (max/min) ______ / ______ km, INCL. ______ deg, TIME ______ hr

BENEFIT OF SPACE TEST: ______________________________

EQUIPMENT: WEIGHT ______ kg, SIZE ______ X ______ X ______ m, POWER ______ kW

POINTING ______ STABILITY ______ DATA ______

ORIENTATION ______ CREW: NO. ______ OPERATIONS/DURATION ______ / ______

SPECIAL GROUND FACILITIES: ______________________________

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ______

9. GROUND TEST OPTION TEST ARTICLE: ______________________________

TEST DESCRIPTION/REQUIREMENTS: ______________________________

SPECIAL GROUND FACILITIES: ______________________________

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ______________________________

TEST CONFIDENCE ______

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION							GROUND TEST OPTION						
								COST ($)							COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ______ (SUM OF PROGRAM COSTS $ ______)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ______

F 1 (1DR-2) 7/75

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. ______ PAGE 1

1. REF. NO. 17 PREP DATE ______ REV DATE ______ LTR ______
CATEGORY Electric Power

2. TITLE Measurement of Solar Radiation Intensity and Spectral Distribution

3. **TECHNOLOGY ADVANCEMENT REQUIRED**

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

Measurement of spectral intensity of solar radiation over range of sensitivity of solar cells (0.2 um to 1.5 um). Some doubt has been cast on presently used spectral intensity of sunshine by limited flight tests of advanced solar cells.

4. **SCHEDULE REQUIREMENTS** FIRST PAYLOAD FLIGHT DATE ______
PAYLOAD DEVELOPMENT LEAD TIME ______ YEARS. TECHNOLOGY NEED DATE ______

5. **BENEFIT OF ADVANCEMENT** NUMBER OF PAYLOADS ______
TECHNICAL BENEFITS Definitive measurement of spectral intensity and total intensity of solar radiation needed to guide future development of high efficiency solar cells.

POTENTIAL COST BENEFITS ______

ESTIMATED COST SAVINGS $ ______

6. **RISK IN TECHNOLOGY ADVANCEMENT**
TECHNICAL PROBLEMS ______

REQUIRED SUPPORTING TECHNOLOGIES ______

7. **REFERENCE DOCUMENTS/COMMENTS** ______

FT (TDR-1) 7/75

TITLE ______ NO. ______

______ PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: ______

TEST DESCRIPTION: ALT. (max/min) ____/____ km, INCL. ____ deg, TIME ____ hr

BENEFIT OF SPACE TEST: ______

EQUIPMENT: WEIGHT ____ kg, SIZE ____ X ____ X ____ m, POWER ____ kW

POINTING ____ STABILITY ____ DATA ____

ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION ____/____

SPECIAL GROUND FACILITIES: ______

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ______

9. GROUND TEST OPTION TEST ARTICLE: ______

TEST DESCRIPTION/REQUIREMENTS: ______

SPECIAL GROUND FACILITIES: ______

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ______

TEST CONFIDENCE ______

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS 2. DESIGN 3. MFG & C/O 4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ______ (SUM OF PROGRAM COSTS $ ______)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ______

F1 (TDR-2) 7/75

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. ______
PAGE 1

1. REF. NO. 17 PREP DATE 8/7/75 REV DATE ______ LTR ____
CATEGORY Electric Power

2. TITLE Environmental Tests of Advanced Solar Cells

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

Verification of space worthiness of improved solar cells. Initial output in space and degradation due to particulate and ultraviolet radiation cannot be convincingly determined in ground tests for many types of cells. Exposure to the real space environment for a year is needed to validate grounds test measurements and to improve the accuracy of ground measurements.

4. SCHEDULE REQUIREMENTS FIRST ~~PAYLOAD~~ experiment FLIGHT DATE ASAP
~~PAYLOAD~~ experiment DEVELOPMENT LEAD TIME initial 2 YEARS. TECHNOLOGY NEED DATE Recurring

5. BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS ______

TECHNICAL BENEFITS Present technology programs aim to reduce the cost of solar cell arrays for conventional missions by 70% and reduce the weight for SEPS mission by 85%. Improved cells for these programs are in development. Space tests are needed to validate the approaches pursued, identify deficiencies early and promote user acceptance. Cells returned from these experiments would be used or standards to set the illumination under solar simulators. Similar

POTENTIAL COST BENEFITS needs will be more critical for development of the SSPS array.

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS ______

REQUIRED SUPPORTING TECHNOLOGIES ______

7. REFERENCE DOCUMENTS/COMMENTS ______

FT (TDR-1) 7/75

TITLE ______________________________ NO. ________

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: ______________________________

TEST DESCRIPTION: ALT. (max/min) ______/______ km, INCL. ______ deg, TIME ______ hr

BENEFIT OF SPACE TEST: ______________________________

EQUIPMENT: WEIGHT ______ kg, SIZE ______ X ______ X ______ m, POWER ______ kW

POINTING ______ STABILITY ______ DATA ______

ORIENTATION ______ CREW: NO. ______ OPERATIONS/DURATION ______/______

SPECIAL GROUND FACILITIES: ______________________________

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ______

9. GROUND TEST OPTION TEST ARTICLE: ______________________________

TEST DESCRIPTION/REQUIREMENTS: ______________________________

SPECIAL GROUND FACILITIES: ______________________________

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ______________________________

TEST CONFIDENCE ______

10. SCHEDULE & COST

TASK	SPACE TEST OPTION							GROUND TEST OPTION						
CY							COST ($)							COST ($)
1. ANALYSIS 2. DESIGN 3. MFG & C/O 4. TEST & EVAL														
TECH NEED DATE														
	GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ______ (SUM OF PROGRAM COSTS $ ______)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ______

F1 (TDR 2) 7/75

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. ______
PAGE 1

1. REF. NO. 17 PREP DATE 8/7/75 REV DATE ______ LTR ____
CATEGORY Electric Power

2. TITLE Environmental Tests of Materials for Advanced Solar Cell Arrays

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

Verification of space worthiness of materials used in construction of advanced solar cell arrays. Materials include flexible substrate materials, new cover and encapsulant materials, and adhesives and cements. The space environment cannot be simulated in total in the laboratory and synergestic and rate effects of temperature, oxygen, UV, and particulate radiation are known to be important to many if not all the candidute materials.

4. SCHEDULE REQUIREMENTS FIRST experiment ~~PAYLOAD~~ FLIGHT DATE ASAP
PAYLOAD DEVELOPMENT LEAD TIME initial 2 years turnabout YEARS. experiment ~~TECHNOLOGY~~ NEED DATE Recurring

5. BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS 6

TECHNICAL BENEFITS Present technology program aim to reduce the cost of solar cell arrays for conventional missions by 70% and reduce the weight for SEPS Missions by 85%. New materials must be used and their optical and mechanical properties must be validated in space. The need will become even more critical for the development of the ultra light weight, 30-year-life array for SSPS.

POTENTIAL COST BENEFITS ______

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS ______

REQUIRED SUPPORTING TECHNOLOGIES ______

7. REFERENCE DOCUMENTS/COMMENTS ______

FT (TDR-1) 7/75

TITLE ______________________________ NO. ______

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: ______

TEST DESCRIPTION : ALT. (max/min) ____ / ____ km, INCL. ____ deg, TIME ____ hr

BENEFIT OF SPACE TEST: ______

EQUIPMENT: WEIGHT ____ kg, SIZE ____ X ____ X ____ m, POWER ____ kW

POINTING ____ STABILITY ____ DATA ____

ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION ____ / ____

SPECIAL GROUND FACILITIES: ______

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ____

9. GROUND TEST OPTION TEST ARTICLE: ______

TEST DESCRIPTION/REQUIREMENTS: ______

SPECIAL GROUND FACILITIES: ______

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ______

TEST CONFIDENCE ____

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS 2. DESIGN 3. MFG & C/O 4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ______ (SUM OF PROGRAM COSTS $ ______)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ______

F1 (1DR 2) 7/75

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. ______
PAGE 1

1. REF. NO. ______ PREP DATE ______ REV DATE ______ LTR ______
CATEGORY ______

2. TITLE Liquid Metal Slip Ring Experiment

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

Demonstrate in space the technology of transferring power across rotating joints by liquid metal slip rings. Ground demonstrations have progressed to the point that a demonstration in space can be conducted.
A separate step of this effort would be to perform a similar space experiment but with the Kilovolt and Kilowatt levels that are needed for SEPS and beyond.

4. SCHEDULE REQUIREMENTS FIRST PAYLOAD FLIGHT DATE 1980
PAYLOAD DEVELOPMENT LEAD TIME ______ YEARS. TECHNOLOGY NEED DATE ______

5. BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS ______

TECHNICAL BENEFITS With ever increasing amounts of power use being projected, each loss in the power train becomes more and more sigr ficant. Conventional transferring of power across a rotating joint, such as from a sun seeking solar array to the spacecraft bus, typically poses limitations such as noise, life, high power loss, stiction and friction. Liquid Metal Slip Rings can significantly alleviate these problems.

POTENTIAL COST BENEFITS ______

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS As a result of ongoing technology efforts there is little technical risk in advancing this to the flight test level.

REQUIRED SUPPORTING TECHNOLOGIES ______

7. REFERENCE DOCUMENTS/COMMENTS Liquid Metal Slip Ring Experiment, LeRC proposal submitted for LDEF.

FT (TDR-1) 7/75

TITLE ______ NO. ______

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: LDEF type article consisting of small solar array, electronics, Liquid Metal Slip Rings, stepping motor.

TEST DESCRIPTION: ALT. (max/min) ____ / ____ km, INCL. ____ deg, TIME ____ hr

LDEF parameters are acceptable.

BENEFIT OF SPACE TEST: Low gravity and environment typical of orbitting spacecraft.

EQUIPMENT: WEIGHT 88 kg, SIZE 18 X 24 X 5 m, POWER self contained kW

POINTING not critical STABILITY not critical DATA ____

ORIENTATION sun side CREW: NO. ____ OPERATIONS/DURATION ____ / ____

SPECIAL GROUND FACILITIES: exist at LeRC

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ____

9. GROUND TEST OPTION TEST ARTICLE: Various ground tests have been and are being conducted, the next logical step is to accomplish a space flight.

TEST DESCRIPTION/REQUIREMENTS: ____

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ____

TEST CONFIDENCE ____

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

FT (TDR-2) 7/75

FUTURE PAYLOAD TECHNOLOGY NO. ______

TESTING AND DEVELOPMENT REQUIREMENT PAGE 1

1. REF. NO. ______ **PREP DATE** ______ **REV DATE** ______ **LTR** ______

CATEGORY ______

2. TITLE Extended and Environmental Testing of Solar Array Mechanisms and Materials

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

A variety of solar array mechanisms (primarily drives) and materials (e.g. structures, lubricants, conductors, insulators) have been flown and are in various levels of ground testing and development. With the anticipated move towards longer life it appears desirable to: select a standard drive configuration to eliminate failures due to configuration differences, and to test that configuration for extended periods, and; evaluate materials' performance in a space environment and as a system rather than a component.

4. SCHEDULE REQUIREMENTS **FIRST PAYLOAD FLIGHT DATE** ______

PAYLOAD DEVELOPMENT LEAD TIME ______ **YEARS. TECHNOLOGY NEED DATE** ______

5. BENEFIT OF ADVANCEMENT **NUMBER OF PAYLOADS** ______

TECHNICAL BENEFITS Life time extensions and increased confidence of solar array mechanisms; evaluation of solar array materials in a realistic environment as a system.

POTENTIAL COST BENEFITS ______

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS ______

REQUIRED SUPPORTING TECHNOLOGIES Materials, structures.

7. REFERENCE DOCUMENTS/COMMENTS ______

FT (TDR-1) 7/75

TITLE ______ NO. ______

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Present and new design solar array drive mechanisms for comparison under load and extended testing; candidate materials for arrays and mechanisms in a representative configuration and environment.

TEST DESCRIPTION: ALT. (max/min) ______ / ______ km, INCL. ______ deg, TIME ______ hr

Not critical

BENEFIT OF SPACE TEST: Evaluation in low gravity and typical space environment for long term effects.

EQUIPMENT: WEIGHT ______ kg, SIZE ______ X ______ X ______ m, POWER ______ kW

POINTING ______ STABILITY ______ DATA ______

ORIENTATION ______ CREW: NO. ______ OPERATIONS/DURATION ______ / ______

SPECIAL GROUND FACILITIES: ______

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ______

9. GROUND TEST OPTION TEST ARTICLE: In work at various locations but often as discrete tests only or not on a comparison basis.

TEST DESCRIPTION/REQUIREMENTS: ______

SPECIAL GROUND FACILITIES: ______

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ______

TEST CONFIDENCE ______

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ______ (SUM OF PROGRAM COSTS $ ______)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ______

FT (TDR-2) 7/75

FUTURE PAYLOAD TECHNOLOGY **NO.** ______

TESTING AND DEVELOPMENT REQUIREMENT **PAGE 1**

1. REF. NO. ______ **PREP DATE** ______ **REV DATE** ______ **LTR** ______

CATEGORY ______

2. TITLE In Space Assembly of High Power, Power Transfer Devices

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

High power transfer across rotating joints such as solar arrays may in the near future depend upon transfer devices such as the Liquid Metal Slip Ring. The LMSR design is driven structurally more by the demands to survive launch loads than by on-orbit loads. Assembly in space could simplify, lighten and make more reliable LMSR's.

4. SCHEDULE REQUIREMENTS **FIRST PAYLOAD FLIGHT DATE** ______

PAYLOAD DEVELOPMENT LEAD TIME ______ **YEARS. TECHNOLOGY NEED DATE** ______

5. BENEFIT OF ADVANCEMENT **NUMBER OF PAYLOADS** ______

TECHNICAL BENEFITS Simplify and lighten the design of LMSR's by making them easily assembled in space by machine, by man or some combination. With the advent of large arrays to be assembled in space (SSPS) this could result in a substantial weight and reliability savings.

POTENTIAL COST BENEFITS ______

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS Devise automated or simple man operated assembly techniques. Must follow space demonstrations of Basic LMSR technology.

REQUIRED SUPPORTING TECHNOLOGIES "Liquid Metal Slip Ring Experiment," LeRC proposal for LDEF.

7. REFERENCE DOCUMENTS/COMMENTS ______

FT (TDR-1) 7/75

TITLE ______________________________ NO. ________

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: LMSR for high power transfer, automated assembler, human observor/participator.

TEST DESCRIPTION: ALT. (max/min) ______ / ______ km, INCL. ______ deg, TIME ______ hr

BENEFIT OF SPACE TEST: Demonstrate technique, benefits by low gravity and space environment.

EQUIPMENT: WEIGHT ______ kg, SIZE ______ X ______ X ______ m, POWER ______ kW

POINTING ______ STABILITY ______ DATA ______

ORIENTATION ______ CREW: NO. ______ OPERATIONS/DURATION ______ / ______

SPECIAL GROUND FACILITIES: ______

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ______

9. GROUND TEST OPTION TEST ARTICLE: ______

TEST DESCRIPTION/REQUIREMENTS: ______

SPECIAL GROUND FACILITIES: ______

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ______

TEST CONFIDENCE ______

10. SCHEDULE & COST

TASK	SPACE TEST OPTION CY						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS														
2. DESIGN														
3. MFG & C/O														
4. TEST & EVAL														
TECH NEED DATE														
	GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ______ (SUM OF PROGRAM COSTS $ ______)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ______

F1 (TDR 2) 7/75

FUTURE PAYLOAD TECHNOLOGY **NO.** ____________

TESTING AND DEVELOPMENT REQUIREMENT **PAGE** 1

1. REF. NO. 17 **PREP DATE** 8/7/75 **REV DATE** ________ **LTR** ____

CATEGORY Electric Power

2. TITLE Environmental Tests of Advanced Solar Cell Modules and Subarrays

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

Verification of space worthiness of improved solar cell arrays, including more efficient and radiation resistant solar cells, new cover and encapsulant materials, flexible substrate materials, and modules or subarrays made from the improved components and using new manufacturing techniques to reduce cost and weight and improve life and reliability. The space environment cannot be simulated in total in the laboratory and synergistic and rate effects of temp., oxygen, UV, and particulate radiation are known to be important to many of the materials to be used.

4. SCHEDULE REQUIREMENTS **FIRST** experiment ~~**PAYLOAD**~~ **FLIGHT DATE** ASAP

experiment ~~**PAYLOAD**~~ **DEVELOPMENT LEAD TIME** initial 2 years turnabout **YEARS. TECHNOLOGY NEED DATE** Recurring

5. BENEFIT OF ADVANCEMENT **NUMBER OF PAYLOADS** ____________

TECHNICAL BENEFITS Present technology programs aim to reduce the cost of solar cell arrays for conventional missions by 70% and reduce the weight for SEPS by 85%. These programs require space tests to validate the space worthiness of the approaches, identify deficiencies early, and promote user acceptance. Similar needs will be more critical for development of the very light weight SSPS array.

POTENTIAL COST BENEFITS ____________

ESTIMATED COST SAVINGS $ ____________

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS ____________

REQUIRED SUPPORTING TECHNOLOGIES ____________

7. REFERENCE DOCUMENTS/COMMENTS ____________

FT (TDR-1) 7/75

TITLE ______________________________ NO. ________

______________________________ PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: ______________________________

____

____

TEST DESCRIPTION : ALT. (max/min) ______ / ______ km, INCL. ______ deg, TIME ______ hr

____

____

BENEFIT OF SPACE TEST: ______________________________

____

EQUIPMENT: WEIGHT ______ kg, SIZE ______ X ______ X ______ m, POWER ______ kW

POINTING ______ STABILITY ______ DATA ______

ORIENTATION ______ CREW: NO. ______ OPERATIONS/DURATION ______ / ______

SPECIAL GROUND FACILITIES: ______________________________

______________________________ EXISTING: YES ☐ NO ☐

______________________________ TEST CONFIDENCE ______

9. GROUND TEST OPTION TEST ARTICLE: ______________________________

____

TEST DESCRIPTION/REQUIREMENTS: ______________________________

____

____

SPECIAL GROUND FACILITIES: ______________________________

____

______________________________ EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ______________________________

____

______________________________ TEST CONFIDENCE ______

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS 2. DESIGN 3. MFG & C/O 4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ______ (SUM OF PROGRAM COSTS $ ______)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

______________________________ ______ ______

______________________________ ______ ______

COST RISK $ ______

FT (TDR 2) 7/75

I. Energy Sources & Conversion (Contd.)

B. Solar & Nuclear Thermo Electric

The following experiments have resulted from the heat source and energy conversion technologies.

1. Demonstration of Emergency Cooling System in Zero Gravity for the Brayton Isotope Power System
2. Demonstration of Brayton Isotope Power System in Pointing Experiment for Large Concentrators
3. Scalable, Free Flying Facility for Testing of High Power Density Components
4. Demonstration of a 500 KWe Solar (Brayton*) Space Power System for Transmitting Electric Power to Earth
5. Demonstration of a 100 KWe Nuclear Space Power System (Brayton, Thermionic) for Electric Power or Propulsion

*Competing Technologies include photovoltaic, Brayton, Rankine and Thermionic energy conversion systems.

The proposed experiments are stepping stones to user acceptability of advanced power systems and are therefore demonstration type experiments. In one case, the demonstration experiment is combined with another technology to increase cost effectiveness of space testing. The experiments recommended cover the entire range of power anticipated, namely from 1-2 KWe range of Brayton Isotope Power Systems to the 100 KWe nuclear system and scaled model of the MWe class system. Since it is not clear which of the competing technologies will surface with the greatest advantages and widest applications, the energy conversion systems selected are tenative.

All experiments are considered opportunity driven.

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. ______
PAGE 1

1. REF. NO. ______ PREP DATE ______ REV DATE ______ LTR ______
CATEGORY Electric Power

2. TITLE Demonstrate Emergency Cooling System in Zero Gravity for Brayton Isotope Power System

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

A meltdown test in space which demonstrates capability of emergency cooling system of Brayton Isotope Power System (BIPS) is required as a first step toward demonstrating BIPS. A heat source capable of providing approximately 2400 watts at temperatures up to 3500°F is required. This is a transient test taking up to 100 hours to complete. High temperature measurements are required. The purpose of this test is to determine the transient temperature of the isotope heat source during activation of the emergency cooling system.

4. SCHEDULE REQUIREMENTS FIRST PAYLOAD FLIGHT DATE 1980
PAYLOAD DEVELOPMENT LEAD TIME 1.5 YEARS. TECHNOLOGY NEED DATE 1981

5. BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS ______

TECHNICAL BENEFITS (a) Will demonstrate passive system which prevents unsafe temperature excursion of isotope fuel (safety related)
(b) Will permit use on payloads for future missions presently planned for RTG power sources.

POTENTIAL COST BENEFITS Development of Brayton Isotope Power System could result in a savings of $6,000 per We for each RTG power source replaced by Brayton.

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS Difficult experiment requiring high temperature heat source and high temperature measurements.

REQUIRED SUPPORTING TECHNOLOGIES High temperature sensing. Transient measurements.

7. REFERENCE DOCUMENTS/COMMENTS

FT (TDR-1) 7/75

TITLE ______ NO. ______

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Meltdown test experiment of multifoil insulation system of Brayton Isotope Power System

TEST DESCRIPTION: ALT. (max/min) 500 / 200 km, INCL. ______ deg, TIME 200 hr

BENEFIT OF SPACE TEST: ______

EQUIPMENT: WEIGHT 100# kg, SIZE 20' dia X 20" Lg X ______ m, POWER 2.4 Kwe kW

POINTING none unless solar STABILITY ______ DATA ______

ORIENTATION heat source CREW: NO. ______ OPERATIONS/DURATION ______ / ______

SPECIAL GROUND FACILITIES: ______

EXISTING: YES ☐ NO ☒

TEST CONFIDENCE ______

9. GROUND TEST OPTION TEST ARTICLE: same as 8

TEST DESCRIPTION/REQUIREMENTS: conduct meltdown test in vacuum facility and one g.

SPECIAL GROUND FACILITIES: Vacuum test chamber

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: Meltdown in earth gravity which may affect transient temperatures

TEST CONFIDENCE ______

10. SCHEDULE & COST

TASK	CY (Space Test Option)						COST ($)	CY (Ground Test Option)						COST ($)
1. ANALYSIS														
2. DESIGN														
3. MFG & C/O														
4. TEST & EVAL							*							
TECH NEED DATE														
GRAND TOTAL							$100K	GRAND TOTAL						

11. VALUE OF SPACE TEST $ ______ (SUM OF PROGRAM COSTS $ ______)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ______

F1 (1DR 2) 7 75

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. ______
PAGE 1

1. REF. NO. ______ **PREP DATE** ______ **REV DATE** ______ **LTR** ______
CATEGORY ______

2. TITLE Demonstration of Brayton Isotope Power in Pointing Experiment for Large Concentrators

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

The Brayton Isotope Power System (BIPS) will be ground demonstrated in the 1977-78 time period. Space demonstration is required for user acceptability. It is possible to combine BIPS with an experiment which develops technology for pointing of large arrays (concentrators). The BIPS will provide basic power for station keeping and pointing. An optical collimator with a light sensor can evaluate pointing capability. The experiment can be run for an extended time period (several years) to prove out capability and life.

4. SCHEDULE REQUIREMENTS **FIRST PAYLOAD FLIGHT DATE** 1980
PAYLOAD DEVELOPMENT LEAD TIME 2 **YEARS. TECHNOLOGY NEED DATE** 1982

5. BENEFIT OF ADVANCEMENT **NUMBER OF PAYLOADS** ______

TECHNICAL BENEFITS a) Demonstrate space capability of BIPS
b) Develop technology for pointing of large arrays (will benefit payloads presently planned for RTGs).

POTENTIAL COST BENEFITS Could result in a savings of $6,000 We for each RTG power source replaced by Brayton.

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS Minimal. System to be ground tested in 1977-78 time period.

REQUIRED SUPPORTING TECHNOLOGIES Guidance and Control

7. REFERENCE DOCUMENTS/COMMENTS ______

FT (TDR 1) 7 75

TITLE ______________________ NO. ______

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Demonstration Test of BIPS coupled with pointing experiment.

.ST DESCRIPTION : ALT. (max/min) ____ / ____ km, INCL. ______ deg, TIME several years hr

Geosynchrousous orbit

BENEFIT OF SPACE TEST: Demonstration & user acceptability

EQUIPMENT: WEIGHT 400# BIPS kg, SIZE ? X ____ X ____ m, POWER 1.2 kW

POINTING ______ STABILITY ______ DATA ______

ORIENTATION ______ CREW: NO. ____ OPERATIONS/DURATION ____ / ____

SPECIAL GROUND FACILITIES: ______

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ______

9. GROUND TEST OPTION TEST ARTICLE: ______

TEST DESCRIPTION/REQUIREMENTS: ______

SPECIAL GROUND FACILITIES: ______

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ______

TEST CONFIDENCE ______

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION							GROUND TEST OPTION						
								COST ($)							COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ______ (SUM OF PROGRAM COSTS $ ______)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ______

1 1 (1DR 2) 7/75

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. ______
PAGE 1

1. REF. NO. ______ **PREP DATE** ______ **REV DATE** ______ **LTR** ______
CATEGORY Electric Power and Thermal Control

2. TITLE Free-Flying Facility for Testing of High-Power Density Components

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

The required technology advancement is a scalable shuttle-launched, free-flying facility for experimentation and demonstration related to high-power-density devices and phenomena. The facility includes a high-power-density source, normally a radioisotope, cooled by a metallic-fluid heat pipes which heats the emitter of a thermionic converter having a collector cooled by a heat-pipe radiator. Some evaluations may require several thermionic-converter, heat-pipe modules which feed their electric outputs to a power processing system that energizes instrumentation, control, data-handling, and transmission equipment needed for the experimentation or demonstration. Replacing a standard component of this facility during fabrication with an experimental element allows testing or (Continued)

4. SCHEDULE REQUIREMENTS **FIRST PAYLOAD FLIGHT DATE** 1980 ST
PAYLOAD DEVELOPMENT LEAD TIME 3 to 4 **YEARS.** **TECHNOLOGY NEED DATE** now

5. BENEFIT OF ADVANCEMENT **NUMBER OF PAYLOADS** ______

TECHNICAL BENEFITS This facility will allow high-power-density testing and verification in space of some essential thermal-control and electric-power components.

POTENTIAL COST BENEFITS The facility enables such testing and verification without large-space-station power.

ESTIMATED COST SAVINGS $ dependent on number of missions

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS a) Radioistope handling (perhaps manifold heat-pipe cooling)
b) Use of heat pipes and converters not verified in space as standard facility components (but verification of these in such a facility is desirable)
c) Scaling to various power levels (solved by varying the number of thermionic-converter, heat-pipe modules)

REQUIRED SUPPORTING TECHNOLOGIES
Thermionic conversion
Metallic-fluid heat pipes
Material selection and evaluation

7. REFERENCE DOCUMENTS/COMMENTS RTOP's 506-24-26 and 506-16-31; NASA, ERDA Thermionic-Conversion Program Reviews; Outlook for Outer Space; Future Payload Technology Requirements Study

FT (TDR-1) 7/75

TITLE ____________________ NO. ______

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Described in 3

TEST DESCRIPTION: ALT. (max/min) ____ / ____ km, INCL. ____ deg, TIME ____ hr

Described in 3

BENEFIT OF SPACE TEST: Described in 5

EQUIPMENT: WEIGHT ____ kg, SIZE ____ X ____ X ____ m, POWER ____ kW

POINTING ____ STABILITY ____ DATA ____

ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION ____ / ____

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ____

9. GROUND TEST OPTION TEST ARTICLE: ____

TEST DESCRIPTION/REQUIREMENTS: Ground evaluation leading to performance-life and verification-testing in space is desirable.

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: Ground tests cannot substitute for space-flight verification

TEST CONFIDENCE ____

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

F1 (1DR 2) 7-75

DEFINITION OF TECHNOLOGY REQUIREMENT NO. ______

1. **TECHNOLOGY REQUIREMENT (TITLE):** Free-Flying Facility for Testing of High-Power Density Components **PAGE OF** 1

3. (Continued)

demonstration of thermal-energy acquisition, transmission, conversion, or rejection or electrical processing, each at high-power densities.

For example, such replacements would enable tests of solar-concentrator models, new heat pipes, improved thermionic converters, radiator modules, or the latest processing developments for low-voltage, high-current power.

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. ______
PAGE 1

1. REF. NO. ______ **PREP DATE** ______ **REV DATE** ______ **LTR** ______
CATEGORY Electric Power

2. TITLE Demonstration of a 500 Kwe Solar Brayton Space Power System (SPS) for Transmitting Electric Power to Earth

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

The dynamic conversion systems are strong candidates for the space power system which will convert solar energy to electric power and microwave energy for beaming to Earth. A model of such a system should demonstrate in space the capabilities of a full sized power system. A scaled model of this system should demonstrate performance, life, reliability, size and weight characteristics in space.

4. SCHEDULE REQUIREMENTS **FIRST PAYLOAD FLIGHT DATE** 1985
PAYLOAD DEVELOPMENT LEAD TIME 3 **YEARS. TECHNOLOGY NEED DATE** ______

5. BENEFIT OF ADVANCEMENT **NUMBER OF PAYLOADS** ______

TECHNICAL BENEFITS a) Reduced weight of system. Directly benefits large space power system.

POTENTIAL COST BENEFITS Substantial reduction in cost of SPS and reduced number of launches to place in orbit.

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS a) Pointing requirement of large concentrator
b) Thirty year life of Turbo machinery
c) Single point failure mode (loss of working fluid)

REQUIRED SUPPORTING TECHNOLOGIES Large structure pointing and control

7. REFERENCE DOCUMENTS/COMMENTS ______

FT (TDR-1) 7/75

TITLE ____________________ NO. ______

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: A model of the Brayton power system for beaming converted solar energy to Earth.

TEST DESCRIPTION: ALT. (max/min) ______ / ______ km, INCL. ______ deg, TIME ______ hr

Geosynchronous orbit

BENEFIT OF SPACE TEST: Demonstration

EQUIPMENT: WEIGHT ______ kg, SIZE ______ X ______ X ______ m, POWER ______ kW

POINTING 0.05 deg. STABILITY 0.05 deg. DATA ______

ORIENTATION Sun CREW: NO. ______ OPERATIONS/DURATION ______ / ______

SPECIAL GROUND FACILITIES: ______

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ______

9. GROUND TEST OPTION TEST ARTICLE: Brayton Power system without concentrator

TEST DESCRIPTION/REQUIREMENTS: Ground test demonstration of Brayton power system without solar concentrator and radiator. Turbomachinery and reciperator will be tested in vacuum with heat added and rejected by simplified means.

SPECIAL GROUND FACILITIES: Large vacuum facility

EXISTING: YES ☒ NO ☐

GROUND TEST LIMITATIONS: Cannot test complete system which receives and concentrates solar energy, converts to high voltage D.C. power, converts to microwave energy for transmittal, receipt and conversion to useful electric form.

TEST CONFIDENCE ______

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ______ (SUM OF PROGRAM COSTS $ ______)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ______

FT (TDR 2) 7/75

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. ______
PAGE 1

1. REF. NO. ______ PREP DATE ______ REV DATE ______ LTR ______
CATEGORY Electric Power

2. TITLE Demonstration of a 100 Kwe Nuclear Space Power System (Brayton Thermionic) for Electric Power or Propulsion.

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

There are certain space missions such as near sun orbit, exploration of distant planets or disposal of hazardous nuclear material which require high specific impulse thrusters. This experiment will demonstrate the capability of the selected nuclear heat source and conversion system resulting from the competing technology efforts. The system will have ready growth to 500 Kwe level and even be adaptable to higher power levels. This experiment should demonstrate performance, life, reliability, size and weight characteristics in space by orbiting in near sun orbit.

4. SCHEDULE REQUIREMENTS FIRST PAYLOAD FLIGHT DATE 1985
PAYLOAD DEVELOPMENT LEAD TIME 3 YEARS. TECHNOLOGY NEED DATE 1990

5. BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS ______
TECHNICAL BENEFITS Provide mission capability not available from any other source.

POTENTIAL COST BENEFITS ______

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT
TECHNICAL PROBLEMS ______

REQUIRED SUPPORTING TECHNOLOGIES ______

7. REFERENCE DOCUMENTS/COMMENTS ______

FT (TDR-1) 7/75

TITLE ______ NO. ______

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: ______

TEST DESCRIPTION: ALT. (max/min) ____ / ____ km, INCL. ____ deg, TIME ____ hr

BENEFIT OF SPACE TEST: ______

EQUIPMENT: WEIGHT ____ kg, SIZE ____ X ____ X ____ m, POWER ____ kW

POINTING ____ STABILITY ____ DATA ____

ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION ____ / ____

SPECIAL GROUND FACILITIES: ______

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ____

9. GROUND TEST OPTION TEST ARTICLE: Nuclear heat source and power conversion system.

TEST DESCRIPTION/REQUIREMENTS: Will require testing facility in vacuum.

SPECIAL GROUND FACILITIES: Large vacuum test facility

EXISTING: YES [X] NO ☐

GROUND TEST LIMITATIONS: none

TEST CONFIDENCE ____

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

F1 (TDR 2) 7/75

I. Energy Sources and Conversion (Contd.)

C. Energy Conversion - Chemical

A significant cost/weight penalty is presently paid on shuttle due to measurement inaccuracies in reactant tanking residuals. The need for more accurate techniques at gauging two phase cryogens is recognized. A test program is formulated using RF resonant cavity mode analysis which should achieve better the $\pm$ 1% accuracy.

FUTURE PAYLOAD TECHNOLOGY NO. ____________

TESTING AND DEVELOPMENT REQUIREMENT PAGE 1

1. **REF. NO.** ____________ **PREP DATE** ________ **REV DATE** ________ **LTR** ____

CATEGORY Electric Power

2. **TITLE** Radio Frequency Mass Quantity Gauging

3. **TECHNOLOGY ADVANCEMENT REQUIRED**

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED
		X

Achieve better than ± 1% accuracy with RF resonant cavity mode analysis technique of gauging two phase cryogens in low gravity fields.

Testing in a low gravity environment is absolutely necessary for the perfection of this technique.

4. **SCHEDULE REQUIREMENTS** **FIRST PAYLOAD FLIGHT DATE** ____________

PAYLOAD DEVELOPMENT LEAD TIME ________ **YEARS. TECHNOLOGY NEED DATE** ________

5. **BENEFIT OF ADVANCEMENT** **NUMBER OF PAYLOADS** ________

TECHNICAL BENEFITS Highly accurate and simple quantity gauging in "o" g has not yet been successfully demonstrated. The obvious advantage of such a system would be a reduction in tanking residuals due to gauging inaccuracies.

POTENTIAL COST BENEFITS On the shuttle, for instance, a 1% increase in accuracy would save 17.5 lbs. of fuel cell reactants. At $50/lb. this would save $875K per flight.

ESTIMATED COST SAVINGS $ ________

6. **RISK IN TECHNOLOGY ADVANCEMENT**

TECHNICAL PROBLEMS Optimization of the best averaging techniques for more than one resonant mode. Development of a signal conditioner and electronics to detect, track and process the frequency info into analog/digital output.

REQUIRED SUPPORTING TECHNOLOGIES ________

7. **REFERENCE DOCUMENTS/COMMENTS** ________

FT (TDR-1) 7/75

TITLE ______ NO. ______

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: An instrumented cryogenic tank to be flown in low earth orbit to verify system operation.

TEST DESCRIPTION: ALT. (max/min) ____ / ____ km, INCL. ____ deg, TIME ____ hr

BENEFIT OF SPACE TEST: Normal (one "g") gravity does not verify system accuracy or operation.

EQUIPMENT: WEIGHT TBD kg, SIZE ____ X ____ X ____ m, POWER ____ kW

POINTING ____ STABILITY ____ DATA ____

ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION ____ / ____

SPECIAL GROUND FACILITIES: None

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE High

9. GROUND TEST OPTION TEST ARTICLE: Flight Article

TEST DESCRIPTION/REQUIREMENTS: Calibration Only

SPECIAL GROUND FACILITIES: None

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: Used to calibrate only.

TEST CONFIDENCE ____

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ______ (SUM OF PROGRAM COSTS $ ______)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ______

LLIDR 2/7/75

II. Power Processing, Distribution, Conversion and Transmissions

In the power processing, distribution, conversion and transmission area of power system performance, four specific mission directed experiment areas have been delineated. These experiments will substantially improve the ability of power systems to meet the projected flight mission requirement.

Significant increases in shuttle sortie experiment payload capability and mission duration can be obtained by not requiring the shuttle to carry sufficient power capability for the total mission time on each flight. Instead a self-contained, unattended utility power station experiment, to be stored in space and used when needed, is proposed. Existing solar array technology and developing shuttle fuel cell capabilities are available to support its design and implementation. As proposed, the power station experiment would be used many times, thereby allowing the experiment cost to be paid for by the reduced number of shuttle sortie flights and the additional payload capability on each flight.

Interactions between the space plasmas and high voltage surfaces (e.g. high voltage solar arrays required for SSPS and solar electric propulsion) must be understood before necessary high voltage technology advances can be realized. In addition, recently identified spacecraft charging phenomena must be understood in order to prelude future spacecraft failures. An experiment to obtain the necessary flight engineering data required is proposed to more fully understand the observed phenomena. A companion experiment would investigate the interaction between thruster generated plasma and high voltage surfaces.

Major advancements are envisioned in the methodology of cooling power system components by including heat pipes as an integral part of the components. Conventional thermal control techniques for cooling electrical components yield excessive temperature drops between the component and the thermal disspation area.

The addition of heat pipes as an integral part of the components could significantly reduce these drops. An experiment is proposed to demonstrate the suitability of integral heat pipe technology in power system componetry designs; extended zero-g lifetime exposure is required to confirm the adequacy of the selected design approach.

In orbit demonstration of the solar electric propulsion system's operational capabilities is outlined. In flight experience will greatly increase user confidence in this advanced propulsion technique, as well as provide additional information or plasma interactions, high voltage system design applications and long term lightweight array performance.

FUTURE PAYLOAD TECHNOLOGY **NO.** ________

TESTING AND DEVELOPMENT REQUIREMENT **PAGE 1**

1. REF. NO. Technology Req't "C" **PREP DATE** 8/8/75 **REV DATE** ______ **LTR** ____

CATEGORY Electric Power

2. TITLE Unattended Utility Po.er Station

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED
4	5	7

Demonstration of technology now in existance (solar arre·) and under development (fuel cell) to provide unattended power producing station capability. No advances beyond present state of the art are ·equired. Long life ($\geq$10 years) operation of the system is required, with periodic shuttle visits to refurbish necessary fuel cell componentry.

4. SCHEDULE REQUIREMENTS **FIRST PAYLOAD FLIGHT DATE** 1981

PAYLOAD DEVELOPMENT LEAD TIME 3 **YEARS. TECHNOLOGY NEED DATE** 1979

5. BENEFIT OF ADVANCEMENT **NUMBER OF PAYLOADS** >50

TECHNICAL BENEFITS Increased shuttle experiment payload capability for extended mission duration as it would not be necessary to carry sufficient energy to power the shuttle for the entire mission duration.

POTENTIAL COST BENEFITS Fewer shuttle launches

ESTIMATED COST SAVINGS $ ________

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS (a) Interaction of 10-20 KWe solar array with regenerative fuel cel. system

(b) Fuel Cell reactant storage

REQUIRED SUPPORTING TECHNOLOGIES (a) Shuttle fuel cell development

(b) Self aligning multipin electrical connector assembly (DTR No. A)

(c) Regenerative fuel cell technology based on shuttle fuel cell development.

7. REFERENCE DOCUMENTS/COMMENTS The 1973 NASA Payload Model

FT (TDR-1) 7/75

TITLE ______________________ NO. ______

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Unattended power station, consisting of a 10-20 KW solar array/regenerative fuel cell system.

TEST DESCRIPTION: ALT. (max/min) 500 / 200 km, INCL. any deg, TIME 10,000 hr

Demonstrate feasibility of long life, unattended power generating stations in orbital operation.

BENEFIT OF SPACE TEST: Long term in orbit demonstration of full size power station operation in flight environment.

EQUIPMENT: WEIGHT 400 kg, SIZE 10 X 10 X 25 m, POWER 10-20 kW

POINTING 1.0 degree STABILITY 0.5 degree DATA -------

ORIENTATION sun pointing CREW: NO. 1 OPERATIONS/DURATION 5 /ea 1 day

SPECIAL GROUND FACILITIES: Large vacuum test chambers

EXISTING: YES [X] NO [ ]

TEST CONFIDENCE 0.9

9. GROUND TEST OPTION TEST ARTICLE: Feasibility small test module of unattended utility power station.

TEST DESCRIPTION/REQUIREMENTS: Fabricate and test scale model power station system.

SPECIAL GROUND FACILITIES: Large vacuum test chambers

EXISTING: YES [X] NO [ ]

GROUND TEST LIMITATIONS: Inability to test full scale power station under orbital environmental conditions.

TEST CONFIDENCE 0.5

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ______ (SUM OF PROGRAM COSTS $ ______)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ______

11 (TDR 2) 7-75

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. ____
PAGE 1

1. REF. NO. ____ **PREP DATE** ____ **REV DATE** ____ **LTR** ____
CATEGORY ____

2. TITLE Sphinx B

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

Obtain the engineering data that is necessary to design electrical systems that can be exposed to the space environment over a wide range of plasma densities and operating voltages and to obtain flight data that will serve as a reference set for future ground testing.

4. SCHEDULE REQUIREMENTS **FIRST PAYLOAD FLIGHT DATE** 1980
PAYLOAD DEVELOPMENT LEAD TIME 4 **YEARS. TECHNOLOGY NEED DATE** 1975

5. BENEFIT OF ADVANCEMENT **NUMBER OF PAYLOADS** 1

TECHNICAL BENEFITS Interactions between plasmas of space and high voltage surfaces must be understood before the necessary high voltage technology advances can be realized. Also, recently identified spacecraft charging phenomena must be understood to prevent, by design, future spacecraft failures.

POTENTIAL COST BENEFITS See LeRC letter "SPHINX B/C Benefits Study," D.J. Shramo to J. Lazar, 5/19/75.

ESTIMATED COST SAVINGS $ ____

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS The technology to accomplish this experiment exists.

REQUIRED SUPPORTING TECHNOLOGIES SPHINX C is a companion experiment

7. REFERENCE DOCUMENTS/COMMENTS LeRC Preliminary Plan for Space Plasma High Voltage Interaction Experiment Satellites (SPHINX B/C), February 28, 1975.

FT (TDR-1) 7/75

TITLE Sphinx B NO. ______

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Sphinx B Spacecraft, Nearly identical to the Sphinx A spacecraft lost on the Proof flight Titan/Centaur launch.

TEST DESCRIPTION: ALT. (max/min) 35,000 / 1000 km, INCL. 18 deg, TIME ______ hr

BENEFIT OF SPACE TEST: Resolve orders of magnitude differences of ground test facilities; obtain data for which ground test facilities are inadequate.

EQUIPMENT: WEIGHT 102 kg, SIZE SELF CONTAINED m, POWER ______ kW

POINTING ______ STABILITY ______ DATA ______

ORIENTATION ______ CREW: NO. ______ OPERATIONS/DURATION ______ / ______

SPECIAL GROUND FACILITIES: Required ground facilities exist at LeRC

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ______

9. GROUND TEST OPTION TEST ARTICLE: Ground tests using all available reasonable facilities have been and are being used. However, orders of magnitude differences result between these facilities which can be resolved only with a test in space.

TEST DESCRIPTION/REQUIREMENTS: ______

SPECIAL GROUND FACILITIES: ______

EXISTING: YES [+] NO ☐

GROUND TEST LIMITATIONS: ______

TEST CONFIDENCE ______

10. SCHEDULE & COST

TASK	CY	Space: 76	77	78	79	1980	COST ($)	Ground:					COST ($)
1. ANALYSIS													
2. DESIGN													
3. MFG & C/O		———	———										
4. TEST & EVAL					Δ—	—Δ	*						
TECH NEED DATE													
GRAND TOTAL							6564K	GRAND TOTAL					

11. VALUE OF SPACE TEST $ see reference (SUM OF PROGRAM COSTS $ ______)

*includes both Sphinx B and C

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ______

LT (TDR 2) 7/75

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. ______
PAGE 1

1. REF. NO. ______ PREP DATE ______ REV DATE ______ LTR ______
CATEGORY ______

2. TITLE Sphinx C

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

Demonstrate in a space environment the technology readiness of the eight centimeter ion thruster system for its station keeping mission.

4. SCHEDULE REQUIREMENTS FIRST PAYLOAD FLIGHT DATE 1980
PAYLOAD DEVELOPMENT LEAD TIME 4 YEARS. TECHNOLOGY NEED DATE 1980

5. BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS ______
TECHNICAL BENEFITS Small ion thruster systems for attitude control and satellites. A space demonstration is necessary to achieve user confidence so that these cost savings can be realized.

POTENTIAL COST BENEFITS See LeRC letter "SPHINX B/C Benefits Study," D.J. Shramo to J. Lazar, 5/19/75.

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT
TECHNICAL PROBLEMS The technology exists.

REQUIRED SUPPORTING TECHNOLOGIES SPHINX B is a companion experiment.

7. REFERENCE DOCUMENTS/COMMENTS LeRC Preliminary Plan for Space Plasma High Voltage Interaction Experiment Satellites (SPHINX B/C), February 28, 1975.

FT (TDR-1) 7/75

TITLE ______ NO. ______

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: SPHINX C SPACECRAFT

TEST DESCRIPTION: ALT. (max/min) 35,000 / 1000 km, INCL. 18 deg, TIME ______ hr

BENEFIT OF SPACE TEST: Demonstrate ion thruster system (including power processor advances) operation in a space environment; investigate interactions of thruster generated plasma and high voltage surfaces.

EQUIPMENT: WEIGHT 216 kg, SIZE SELF CONTAINED ______ m, POWER ______ kW

POINTING ______ STABILITY ______ DATA ______

ORIENTATION ______ CREW: NO. ______ OPERATIONS/DURATION ______ / ______

SPECIAL GROUND FACILITIES: Required ground facilities exist at LeRC

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ______

9. GROUND TEST OPTION TEST ARTICLE: Ground tests on components and systems have been and are being conducted full scale.

TEST DESCRIPTION/REQUIREMENTS: However, facility limitations are significantly severe that plasma interactions cannot be accurately investigated.

SPECIAL GROUND FACILITIES: ______

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ______

TEST CONFIDENCE ______

10. SCHEDULE & COST

TASK	CY		76	77	78	79	80	SPACE TEST OPTION COST ($)						GROUND TEST OPTION COST ($)
1. ANALYSIS														
2. DESIGN			———	———										
3. MFG & C/O					———	———								
4. TEST & EVAL							——							
TECH NEED DATE								*						
GRAND TOTAL								6564K	GRAND TOTAL					

11. VALUE OF SPACE TEST $ See reference (SUM OF PROGRAM COSTS $ ______)

*includes both SPHINX B and C

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ______

F 1 (1 DR 2) 7/75

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. ______
PAGE 1

1. REF. NO. ______ PREP DATE ______ REV DATE ______ LTR ______
CATEGORY ______

2. TITLE Flight Demonstration of Power System Components cooled by Integral Heat Pipes

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

Demonstrate a major advancement in cooling power system components by including heat pipes as an integral part of the components. Some of the components to be considered are transistors, thrustors, magnetics, fuel cells, batteries.

4. SCHEDULE REQUIREMENTS FIRST PAYLOAD FLIGHT DATE ______
PAYLOAD DEVELOPMENT LEAD TIME ______ YEARS. TECHNOLOGY NEED DATE ______

5. BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS ______

TECHNICAL BENEFITS Conventional thermal control techniques in use today for cooling components yield temperature drops from cirtical area (e.g., semiconductor junction temp., transformer hot spot temp) to mounting area of perhaps 50 to 75 degrees. Consequently these major heat producing components are limiting factors in thermal design. The addition of heat pipes as integral

~~POTENTIAL COST BENEFITS~~ parts of the components could reduce these drops to perhaps 5 to 10 degrees. Consequently the thermal design time can be greatly reduced; component lifetime limitations and test would be simplified. Significant cost savings and reliability improvements would accrue.

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS Learn how to integrate the heat pipes with the components so as to minimize thermal drops; learn how to effectively electrically isolate where needed.

REQUIRED SUPPORTING TECHNOLOGIES Heat pipes.

7. REFERENCE DOCUMENTS/COMMENTS ______

FT (TDR-1) 7/75

TITLE ______ NO. ______

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: A suitably designed power system with heat pipes as a part of the major power dissipating components, and with suitable instrumentation.

TEST DESCRIPTION: ALT. (max/min) ____ / ____ km, INCL. ____ deg, TIME ____ hr

BENEFIT OF SPACE TEST: Primarily to use the zero g aspects of space, but also to demonstrate this approach to potential users and designers.

EQUIPMENT: WEIGHT ____ kg, SIZE ____ X ____ X ____ m, POWER ____ kW

POINTING ____ STABILITY ____ DATA ____

ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION ____ / ____

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ____

9. GROUND TEST OPTION TEST ARTICLE: ____

TEST DESCRIPTION/REQUIREMENTS: Some ground tests can be performed but heat pipe operation in a 1 g field imposes certain limitations that can be alleviated only in space.

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: 1 g field

TEST CONFIDENCE ____

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

F1 (TDR 2) 7/75

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. ________
PAGE 1

1. REF. NO. ________ **PREP DATE** ________ **REV DATE** ________ **LTR** ____
CATEGORY ________

2. TITLE SEPS Prime Propulsion Demonstration

3. TECHNOLOGY ADVANCEMENT REQUIRED

Demonstrate for potential users the primary propulsion thrust subsystem under development.

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

4. SCHEDULE REQUIREMENTS **FIRST PAYLOAD FLIGHT DATE** Early 80's

PAYLOAD DEVELOPMENT LEAD TIME ________ **YEARS. TECHNOLOGY NEED DATE** ________

5. BENEFIT OF ADVANCEMENT **NUMBER OF PAYLOADS** ________

TECHNICAL BENEFITS A primary propulsion thrust subsystem is currently under development. The risks of flying this subsystem on an operational mission may be too large for many potential project managers to assume. These risks can be significantly reduced by conducting a demonstration flight. Further benefits would accrue for related technologies such as solar array voltage outputs ********************** up to 400 V, plasma interactions with 30 cm thrusters, 3 Kw/unit power processing, light weight arrays, ion thruster operations.

ESTIMATED COST SAVINGS $ ________

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS Technology to accomplish the thrust subsystem experiment should be in hand by 1979.

REQUIRED SUPPORTING TECHNOLOGIES Many.

7. REFERENCE DOCUMENTS/COMMENTS LeRC Program Plan for Primary Propulsion Thrust Subsystem.

FT (TDR-1) 7/75

TITLE ____________________ NO. ________

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Thrust subsystem with necessary ancillary equipment.

TEST DESCRIPTION: ALT. (max/min) ____ / ____ km, INCL. ____ deg, TIME ____ hr

BENEFIT OF SPACE TEST: Demonstrate capabilities and reliability for potential users

EQUIPMENT: WEIGHT ____ kg, SIZE ____ X ____ X ____ m, POWER 20 kW

POINTING ____ STABILITY ____ DATA ____

ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION several/ years

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ____

9. GROUND TEST OPTION TEST ARTICLE: Ground facilities can be used for extensive tests but are inadequate for final confidence demonstrations.

TEST DESCRIPTION/REQUIREMENTS: ____

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ____

TEST CONFI... NCE ____

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

F 1 (1DR 2) 7/75

III. Storage

The Power Working Group has identified two technology testing and development requirements for space testing. Both of these requirements are in the electrochemical technology area. They are primarily concerned with electrolyte distribution, electrode material stability and retention, and gas bubble coverage of electrodes in the zero "g" environment.

FUTURE PAYLOAD TECHNOLOGY **NO.** ______

TESTING AND DEVELOPMENT REQUIREMENT **PAGE 1**

1. **REF. NO.** GE-17.5 **PREP DATE** 8/6/75 **REV DATE** ______ **LTR** ______

CATEGORY Electric Power

2. **TITLE** Silver Zinc Cell Experiment

3. **TECHNOLOGY ADVANCEMENT REQUIRED**

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED
4	5	7

Data must be obtained for the design of reliable (zero "g") high-rate, Ag-Zn cells for probe applications, synchronous orbits and 24 hr. orbits. Improved life at lower temperatures (0° C-15°C) is certain. The reliability of the cells under zero "g" and quantitative performance data are needed to achieve the lowest possible design weight. Problems are: Zinc electrode deterioration and dendritic growth, silver migration, internal gassing and a limited temperature range.

4. **SCHEDULE REQUIREMENTS** **FIRST PAYLOAD FLIGHT DATE** 1979

PAYLOAD DEVELOPMENT LEAD TIME 2 **YEARS. TECHNOLOGY NEED DATE** 1980

5. **BENEFIT OF ADVANCEMENT** **NUMBER OF PAYLOADS** ______

TECHNICAL BENEFITS Lightweight reliable Ag-Zn batteries for probe applications and as an alternate to metal/gas batteries for orbital applications. Weight savings 1/2 to 1/3 of Ni compared to Cd batteries.

POTENTIAL COST BENEFITS Weight savings, increased reliability

ESTIMATED COST SAVINGS $ 50-100k/spacecraft

6. **RISK IN TECHNOLOGY ADVANCEMENT**

TECHNICAL PROBLEMS Deterioration of the zinc electrode.
Limited temperature range.

REQUIRED SUPPORTING TECHNOLOGIES ______

7. **REFERENCE DOCUMENTS/COMMENTS** "Gravitational Effects on Electrochemical Batteries," Meredith, Robert E., Juvinall, Gordon L., and Uchiyama, A.A.; JPL Technical Report 32-1570. "Reduced Gravity Battery Test Program," Final Report, Contract 952121, The General Electric Company. "The Effect of Weightlessness on the Performance of Batteries and Fuel Cells," Eisenberg, Morris Proceedings of the 12th Annual Battery R & D Conference; U.S. Army Signal Lab, 1958.

FT (TDR-1) 7/75

TITLE Silver Zinc Cell Experiment

NO. ______

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Silver-zinc, 16 amp-hour sealed cell with reference electrode and pressure transducers and thermistors.

TEST DESCRIPTION: ALT. (max/min) 200 / 400 km, INCL. NA deg, TIME NA hr

BENEFIT OF SPACE TEST: Exposure to zero g.

EQUIPMENT: WEIGHT 5 kg, SIZE 0.5 X 0.5 X 0.9 m, POWER 0.1 kW

POINTING NA STABILITY .05g DATA ______

ORIENTATION NA CREW: NO. ______ OPERATIONS/DURATION /

SPECIAL GROUND FACILITIES: Test eqpt.

EXISTING: YES [ ] NO [X]

TEST CONFIDENCE 95%

9. GROUND TEST OPTION TEST ARTICLE: NA

TEST DESCRIPTION/REQUIREMENTS: ______

SPECIAL GROUND FACILITIES: ______

EXISTING: YES [ ] NO [ ]

GROUND TEST LIMITATIONS: ______

TEST CONFIDENCE ______

10. SCHEDULE & COST

SPACE TEST OPTION

TASK / CY	76	77	78	79			COST ($)
1. ANALYSIS	20						
2. DESIGN		20					
3. MFG & C/O			40				
4. TEST & EVAL				40			
TECH NEED DATE							
GRAND TOTAL							120K

GROUND TEST OPTION

TASK / CY							COST ($)
1. ANALYSIS							
2. DESIGN							
3. MFG & C/O							
4. TEST & EVAL							
TECH NEED DATE							
GRAND TOTAL							

11. VALUE OF SPACE TEST $ 500K (SUM OF PROGRAM COSTS $ ______)

12. DOMINANT RISK/TECH PROBLEM

DOMINANT RISK/TECH PROBLEM	COST IMPACT	PROBABILITY
Deterioration of Zinc Electrode	200K	0.5

COST RISK $ 100K

F1 (TDR 2) 7/75

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. ____
PAGE 1

1. **REF. NO.** GE 17.5 **PREP DATE** June '75 **REV DATE** 8/8/75 **LTR** ____
CATEGORY Electric Power

2. **TITLE** High Energy Density Battery Experiment

3. **TECHNOLOGY ADVANCEMENT REQUIRED**

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED
4	5	7

Battery weight improvements in the order of 50% are required for automated spacecraft missions of several years duration. The metal/gas batteries will meet these requirements but must be qualified in space if they are to be used. It must be demonstrated that the cells will reliably discharge and accept charges efficiently after long periods of weightlessness. The electrolyte must be managed so as to prevent flooding the negative electrode during discharge and to prevent bubble coverage of the negative electrode during charge.

4. **SCHEDULE REQUIREMENTS** **FIRST PAYLOAD FLIGHT DATE** 1979
PAYLOAD DEVELOPMENT LEAD TIME 2 **YEARS. TECHNOLOGY NEED DATE** 1980

5. **BENEFIT OF ADVANCEMENT** **NUMBER OF PAYLOADS** 120 (8 per yr. 1978-1991)
TECHNICAL BENEFITS 1. Higher energy density
2. Simpler charge control

POTENTIAL COST BENEFITS Simple charge control system
Higher energy density

ESTIMATED COST SAVINGS $ 200k per spacecraft

6. **RISK IN TECHNOLOGY ADVANCEMENT**
TECHNICAL PROBLEMS Bubble coverage of negative electrode could prevent efficient charge of nickel-hydrogen cell.
Silver migration, water formation could mean shorter life for silver-hydrogen cells.

REQUIRED SUPPORTING TECHNOLOGIES Liquid management in zero "g"

7. **REFERENCE DOCUMENTS/COMMENTS**
Future Payload Tech Req. CASO-NAS-75-004 June, 1975.
(Continued)

FT (TDR 1) 7/75

TITLE High Energy Density Battery Experiment — NO. ____ PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

° **SPACE TEST OPTION** TEST ARTICLE: Reduced gravity Battery Test System

TEST DESCRIPTION: ALT. (max/min) 500 / 200 km, INCL. NA deg, TIME ____ hr

BENEFIT OF SPACE TEST: Exposure to zero "g" experiment

EQUIPMENT: WEIGHT 59 kg, SIZE 0.5 X 0.7 X 0.9 m, POWER 0.5 kW

POINTING ____ STABILITY 6.05 DATA ____

ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION 3 yrs. /

SPECIAL GROUND FACILITIES: None

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE 0.9

9. **GROUND TEST OPTION** TEST ARTICLE: NA

TEST DESCRIPTION/REQUIREMENTS: ____

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ____

TEST CONFIDENCE ____

10. **SCHEDULE & COST**

TASK	CY	Space Test Option						COST ($)	Ground Test Option						COST ($)
1. ANALYSIS															
2. DESIGN															
3 MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. **VALUE OF SPACE TEST $** ____ (SUM OF PROGRAM COSTS $ ____)

12. **DOMINANT RISK/TECH PROBLEM** COST IMPACT PROBABILITY

COST RISK $ ____

11 (1DR 21 / 75

DEFINITION OF TECHNOLOGY REQUIREMENT NO. ______

1. TECHNOLOGY REQUIREMENT (TITLE): High Energy Density Battery Experiment

7. REFERENCE DOCUMENTS/COMMENTS (Continued)

"Gravitational Effects on Electrochemical Batteries," Meredith, Robert E., Juvinall, Gordon L., and Uchiyama, A.A.; JPL Technical Report 32-1570.

"Reduced Gravity Battery Test Program," Final Report, Contract 952121, The General Electric Company.

"The Effect of Weightlessness on the Performance of Batteries and Fuel Cells," Eisenberg, Morris Proceedings of the 12th Annual Battery R & D Conference; U.S. Army Signal Lab, 1958.

"The Sealed Nickel-Hydrogen Secondary Cells," Giver, Jose, and Dunlop, James D., J. Electrochemical Society 122 No. 1, p. 4, 1975.

"A Nickel-Hydrogen Secondary Cell for Synchronous Orbit Application," Storkel, J. F., Van Omunering, Swette, L., and Gaines, L. 8th IECEC Conference, 1973 Proceedings, p. 87.

"Nickel Hydrogen Battery System," Klein, M., and Baker, B. S., 9th IECEC Conference, 1974 Proceedings, p. 118.

"Nickel-Hydrogen Battery Development for Synchronous Satellites," Gandel, M. G., Chang, R., and Farsch, W. C., ibid. p. 123.

BOOK II: MISSION DRIVEN TECHNOLOGY

I. Energy Sources and Conversion

A. Advanced Technology Requirements for Photovoltaics

The Solar Electric Propulsion System (SEPS) planned for use on the Enke Rendezvous Payload (PL-24, 1973 Mission Model) requires an 85% weight reduction of the solar cell arrays. This can be accomplished by developing advanced silicon solar cells and light weight array support structures. Advancements of silicon solar cell technology include increased initial and end-of-life efficiencies (i.e., increased radiation hardness) and decreased cell weight. Proposed work on silicon cells includes reduction of photon reflection, use of thin cells and thin radiation covers, and increased open circuit voltage. Advancements of solar array support structures include improvement of array fabrication methods, development of light weight, deployable structures, and improvement of power transfer across rotating joints. Naturally, these improvements in specific mass (mass/power) are also applicable to the Space Satellite Power Station discussed in the Report of the Outlook for Space Study, July, 1975.

Various Inner Planet missions presently planned (PL 10,11,12,13,14) require solar cells capable of operating reliably at elevated temperatures. Therefore, III-V Compound Semiconductor cells can be developed to meet this requirement. These devices will also provide high efficiency cells for lower temperature operation and for higher temperature operation in conjunction with solar concentrators. Therefore, these cells will make prime candidates for use in the Space Satellite Power Station.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. ____

1. TECHNOLOGY REQUIREMENT (TITLE): Solar Cell Array for Solar Electric Propulsion PAGE 1 OF ___

2. TECHNOLOGY CATEGORY: Electric Power

3. OBJECTIVE/ADVANCEMENT REQUIRED: Solar cell array blanket and support structure of high power / mass ratio and large area.

4. CURRENT STATE OF ART: State of the art arrays are too heavy. Present arrays are designed for low voltage.

HAS BEEN CARRIED TO LEVEL ___

5. DESCRIPTION OF TECHNOLOGY

Deployable (and perhaps retractable) solar cell arrays and supporting structures must be developed for electric propulsion applications. Required power level is 20 - 50 KW and power mass ratio 200 w/Kg. Array flown has been 44 w/Kg and another array with a ratio of 66 w/Kg has been developed. Design studies show feasibility of 110w/Kg. This advancement requires further improvement in efficiency of thin cells, reduction of cover thickness, improvement of array fabrication methods, and development of light weight, deployable structures.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☒ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. The design gap of 110 w/Kg was selected as an optimistic upper limit based on conceptual study of large array systems. The retractable option allow optimal use of the solar array for primary power in a low Earth orbit to geosynchronous orbit transportation systems.
b. The very large class of high power geosynchronous satellites, electric propulsion transportation stages and interplanetary spacecraft would strongly benefit from this technology.
c. The decrease in specific mass of solar array system would result in payload increases in excess of the reduction of solar array mass via the capability of use of increased specific impulse propulsion systems.
d. This technology should be carried to a space test on the shuttle or an automated spacecraft.

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT NO.

1. **TECHNOLOGY REQUIREMENT(TITLE):** Solar Cell Array for Solar Electric Propulsion

7. **TECHNOLOGY OPTIONS:**

The use of unconditioned solar array power for the large source levels would strongly benefit systems. For solar electric propulsion of a significant weight saving (20 percent) would be achieved for the thrust subsystem.

8. **TECHNICAL PROBLEMS:**

Getting high efficiency from thin cells
Fabricative handling and assembly of thin cells
Thin cover or encapsulant for solar cells
Light weight structural materials
Rigidity and dynamics of light weight structure

9. **POTENTIAL ALTERNATIVES:**

Chemical propulsion with reduced payload for same missions. Some missions require electric propulsion and would have to await nuclear electric propulsion.

10. **PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANC NT:**

EXPECTED UNPERTURBED LEVEL __

11. **RELATED TECHNOLOGY REQUIREMENTS:**

Guidance, Navigation and Control of large, flexible spacecraft
Structural dynamics of large flexible spacecraft
Advanced power management technology.

DEFINITION OF TECHNOLOGY REQUIREMENT	NO.

1. TECHNOLOGY REQUIREMENT (TITLE): Solar Cell Array for Solar Electric Propulsion PAGE 3 OF ___

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1.																			
2.																			
3.																			
4.																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																	TOTAL
TECHNOLOGY NEED DATE																	
NUMBER OF LAUNCHES																	

14. REFERENCES:

1. Report on the status and prospects of the NASA Space Power and Propulsion Research Technology Program. Volume Two. Program status and prospects, 30 May 1975.

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. ____

1. TECHNOLOGY REQUIREMENT (TITLE): High Efficiency, Low Cost, Radiation Resistant, Light-Weight, Si Solar Cells PAGE 1 OF __

2. TECHNOLOGY CATEGORY: Electric Power

3. OBJECTIVE/ADVANCEMENT REQUIRED: Increase initial and end-of-life power conversion efficiencies (η_I and η_{EOL}, respectively) of solar cells to η_I = 18% and η_{EOL} = 16%.

4. CURRENT STATE OF ART: η_I = 15% AMO and η_{EOL} = 11.5% for present laboratory silicon cells. η_I = 14.7% for GaAs Hetercface cells.

HAS BEEN CARRIED TO LEVEL __

5. DESCRIPTION OF TECHNOLOGY

The required new technology is to increase η_I to 18% AMO and η_{ECL} to 16% AMO by one or more of the following approaches:

1. Texturized, non-reflective (Black) cell.
2. Solution of open circuit voltage problem.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. Improved η_I and η_{EOL} will significantly decrease the number of cells needed to achieve specified power requirements, and therefore will increase power to weight ratios for future solar cell arrays.

b. Missions requiring solar electric power, and particularly missions requiring solar electric propulsion, e.g. The Comet Encke Rendezvous (PL-24, 1973 Mission Model).

c. Advancement will decrease weight and maintain power output of future solar cell arrays. Also, reliability of future arrays will be increased, particularly in space radiation environments.

d. Simple processes and techniques amendable to high volume production need to be developed for processing and handling very thin cells. (Level 9-10)

TO BE CARRIED TO LEVEL __

DEFINITION OF TECHNOLOGY REQUIREMENT	NO.

1. **TECHNOLOGY REQUIREMENT(TITLE):** ______________________ **PAGE 2 OF** __

7. TECHNOLOGY OPTIONS:

Power systems utilizing cells of reduced η_I and η_{EOL} will require more cells to supply required power. Also, reduction of η_{EOL} will reduce system reliability in a space radiation environment.

8. TECHNICAL **PROBLEMS:**

a. Obtaining uniform processing of cells.
b. Reduction of cell breakage during handling.
c. Increasing Open Circuit Voltage of cell.

9. POTENTIAL ALTERNATIVES:

10. **PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:**

EXPECTED UNPERTURBED LEVEL 8

11. RELATED TECHNOLOGY REQUIREMENTS:

DEFINITION OF TECHNOLOGY REQUIREMENT NO. ____

1. TECHNOLOGY REQUIREMENT (TITLE): Power Transfer Across Rotating Joints PAGE 1 OF ___

2. TECHNOLOGY CATEGORY: Electric Power

3. OBJECTIVE/ADVANCEMENT REQUIRED: Improve the technology of transferring power across solar array to spacecraft rotation joints.

4. CURRENT STATE OF ART: Sliding contact, mechanical slip rings are conventionally used in space.

HAS BEEN CARRIED TO LEVEL ___

5. DESCRIPTION OF TECHNOLOGY

Liquid metal slip rings offer a potential significant advancement in reducing noise, power loss, friction and in extending life. The technology is in work and has shown clearly the potentials indicated by theory.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

A) Sliding contact, mechanical slip rings have been developed to the point of extensive use in space. However their weaknesses in noise, power loss, friction and life warrant efforts to develop alternate approaches.

B) SEPS, high power microwave TWT's and SSPS can potentially benefit.

TO BE CARRIED TO LEVEL ___

DEFINITION OF TECHNOLOGY REQUIREMENT NO.

1. TECHNOLOGY REQUIREMENT(TITLE): Power Transfer Across Rotating Joints

7. TECHNOLOGY OPTIONS:

Various mechanical configurations of slip rings havn been proposed.

8. TECHNICAL PROBLEMS:

Contamination due to handling of gallium

Designing for 1 g and launch loads

9. POTENTIAL ALTERNATIVES:

Continue with mechanical slip ring contacts.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

This effort in work at LeRC. A flight experiment has been proposed for LDEF.

EXPECTED UNPERTURBED LEVEL __

11. RELATED TECHNOLOGY REQUIREMENTS:

DEFINITION OF TECHNOLOGY REQUIREMENT	NO.

1. TECHNOLOGY REQUIREMENT (TITLE): Power Transfer Across Rotating Joints

PAGE 3 OF

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Ground Tests & Development																			
2. Flight Exp. Preps																			
3.																			
4.																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																		TOTAL
TECHNOLOGY NEED DATE																		
NUMBER OF LAUNCHES																		

14. REFERENCES:

LeRC proposal for LDEF experiment "Liquid Metal Slip Ring Experiment."

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

ADVANCED TECHNOLOGY REQUIREMENT FORM

1. High Temperature, High Efficiency, Radiation Resistant III-V Compound Solar Cells.

2. Electrical Power

3. Develop High Temperature (300°C)

   Solar cell capability to yield a space efficiency at 300°C (η_{300}) of 8%.

4. The best laboratory AlGaAs-GaAs Heteroface cell efficiency at 250°C is 8%. Silicon cells have no output at this temperature.

5. The required new technology is to increase η_{300} to 8%. by one or more of the following efforts persued using AlGaAs-GaAs systems:

   a. Heteroface cells.
   b. Single Graded Band-Gap Cells.

6. a. The capability of operating solar cells efficiently at 300° will facilitate use of solar cell power systems on near-sun/high radiation mission. High temperature solar cells will reduce or eliminate the need for special constraints (such as satellite orientation for cooling cells) on the satellite designer.

   b. Missions requiring solar electric power, particularly near-sun/high particle radiation mission; e.g. Inner Planet missions (PL-10, 11,12,13,14 in 1973 Mission Model).

   c. Advancement will provide a new capability of efficient solar cell operation up to 300°C. Also, advancement will decrease weight, increase reliability in space particle radiation environments while maintaining power output of future solar cell arrays.

   d. This technology will be carried through level 7.

7. Reduction of cell efficiency at 300°C may require return to schemes for pointing satellite solar power systems away from the sun. This will require additional array area to maintain the required power level.

8. a. Growing thin layers of III-V material of both uniform and graded composition material.

   b. Passivation of exposed surface

   c. Maintaining simplicity of processing techniques.

9. Radioisotope thermal generator and (possibly) silicon solar cells.

10. RTOPs 506-18-21
506-16-13

11. None

12. "High Efficiency Graded Band-Gap $Al_xGa_{1-x}As$-GaAs Solar Cell," by J. A. Hutchby, Applied Physics Letters, 26, 457 (1975).

"High Efficiency Graded Band-Gap $Al_xGa_{1-x}As$-GaAs Solar Cell," by J. A. Hutchby, 11th IEEE Photovoltaic Specialists Conference (1975).

1973 Mission Model

"$Ga_{1-x}Al_xAs$-GaAs P-P-n Heterojunction Solar Cells," by H. J. Hovel and J. M. Woodall, J. Electrochem. Soc. 120, 1240 (1973).

I. Energy Source and Conversion

B. Solar and Nuclear Thermal Electric

No technology areas were identified.

I. Energy Sources and Conversion

C. Chemical Power Systems

A hydrogen, oxygen fuel cell selected to provide TUG primary electric power at approximately 10 lb/kw will use propulsion-grade reactants. Because these propellants should not be fed directly to the alkaline fuel cell, ancillary processing must be developed, possibly by modifying a Shuttle scrubber. After effecting design changes indicated by engineering-model evaluations, powerplants will be fabricated for performance, life-, and confidence-testing.

A second requirement is low-gravity radio-frequency mass **gauging of** stratified-supercritical or two-phase cryogens, which are not measurable by capacitance methods. This new technique offers potentials for $\pm$ 1% accuracies and significant weight savings on the TUG. Although early engineering models were tested up to 30 seconds in NASA low-gravity aircraft flights, orbital verification is required.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. ______

1. TECHNOLOGY REQUIREMENT (TITLE): Hydrogen/Oxygen Fuel Cell Module for TUG PAGE 1 OF __

2. TECHNOLOGY CATEGORY: Electric Power

3. OBJECTIVE/ADVANCEMENT REQUIRED: Develop light weight fuel cell module.

4. CURRENT STATE OF ART: Latest state-of-the-art is the Shuttle fuel cell which is approximately 29 pounds per steady state kilowatt.

HAS BEEN CARRIED TO LEVEL __

5. DESCRIPTION OF TECHNOLOGY

Fuel cells have provided reliable power for the Gemini and Apollo missions, including Skylab and ASTP. These early concepts were heavy, low power devices which were short-lived and cumbersome. An asbestos matrix alkaline cell is being developed for the Shuttle with a power rating of 2 to 12 kw. The reactants must be high purity H_2&O_2 and have an extremely low content of carbon bearing compounds. A fuel cell with a lower power rating and a lighter specific weight is required for TUG. The advanced electrode technology has been developed to a point where a module should be fabricated and tested.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☒ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

1. Use of propulsion grade reactants in the TUG fuel cell will eliminate the need for separate, dedicated fuel cell tankage, resulting in lower system weights. Technology in this area should be directed toward devices which will provide an uninterrupted flow of reactants in a "0" gravity environment.

2. Further weight reductions are required in ancillary component such as regulators, pumps and valves to be compatible with an advanced electrode fuel cell.

TO BE CARRIED TO LEVEL __

DEFINITION OF TECHNOLOGY REQUIREMENT NO.

1. TECHNOLOGY REQUIREMENT(TITLE): Hydrogen/Oxygen Fuel Cell for TUG

7. TECHNOLOGY OPTIONS:

The technology options available are:

1. Advanced electrode from NAS3-15339
2. Modified Shuttle fuel cell module
3. Ion exchange membrane concept.

8. TECHNICAL PROBLEMS:

1. To date only single cells and small stacks have been tested. Stacking and performance problems must be defined in an engineering model test.

9. POTENTIAL ALTERNATIVES:

1. Use an unmodified shuttle fuel cell.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

1. NAS3-15339 is a technology effort with Power System Div. of UTC to develop the advanced electrode (strip cell).
2. A related development program underway is the Shuttle Mainstream fuel cell managed by Rockwell Int.

EXPECTED UNPERTURBED LEVEL __

11. RELATED TECHNOLOGY REQUIREMENTS:

1. A related technology effort is in the area of catalysts development. A more stable long life catalyst will compliment the TUG fuel cell technology.

DEFINITION OF TECHNOLOGY REQUIREMENT NO.

1. TECHNOLOGY REQUIREMENT (TITLE): Hydrogen/Oxygen Fuel Cell Module for TUG

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Dev. Program			750k																
2. Life Confidence Testing & Design					1.2m														
3. Flight Qual.																			
4.																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																	TOTAL
TECHNOLOGY NEED DATE																	
NUMBER OF LAUNCHES																	

14 REFERENCES:

FUNDING

FY 76	$550K	Dev. Prog.
FY 77	700K	
FY 78	750K	
FY 79	1.2M	Life Test
FY 80	1.5M	
FY 81	2.5M	Flt. Qual.
FY 82	1.0M	

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. ______

1. TECHNOLOGY REQUIREMENT (TITLE): Radio Frequency Mass Quantity Gauging PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Electric Power

3. OBJECTIVE/ADVANCEMENT REQUIRED: Achieve better than ± 1% accuracy with RF resonants cavity mode analysis technique of gauging 2¢ cryogens in low gravity fields.

4. CURRENT STATE OF ART: No technique exists which can gauge 2 phase cryogens in a low gravity field.

HAS BEEN CARRIED TO LEVEL __

5. DESCRIPTION OF TECHNOLOGY

A fluid container is, regardless of its shape, resonant at a number of different frequencies of electromagnetic energy. The freq. for a given resonant mode is a function of the size and shape of the cavity, the antenna shape, and the density and geometry of the fluid mass. For a given tank configuration, the dependent variables become density and geometry of the fluid. By tracking the freq. of one resonance in one "g", the density is easily determined. The resonant freq. from more than one resonant mode is used via various averaging techniques to reduce the dependency of the mass geometry variable for 2 phase or stratified supercritical fluids, thus improving accuracy.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☒ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

Highly accurate and simple quantity gauging in low gravity environments has not yet been successfully demonstrated. The obvious advantage of such a system would be a reduction in tanking residuals caused by gauging inaccuracies. A 1% increase in accuracy on the shuttle power reactant storage assembly (fuel cell tanks) results in a 17.5 lb wt. saving. Improved accuracy would also simplify ground servicing equipment.

This technology can be used on the TUG.

TO BE CARRIED TO LEVEL __

DEFINITION OF TECHNOLOGY REQUIREMENT NO.

1. **TECHNOLOGY REQUIREMENT(TITLE):** Radio Frequency Mass Quantity Gauging PAGE 2 OF 3

7. TECHNOLOGY OPTIONS:

Nuclear gauging systems are heavy and have safety disadvantages. Capacitance systems are limited to single phase fluids.

8. TECHNICAL **PROBLEMS:**

Optimization of the best averaging technique for more than one resonant mode. Development of a signal conditioner and electronics to detect, track and process the frequency info into analog/digital output.

9. POTENTIAL ALTERNATIVES:

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

EXPECTED UNPERTURBED LEVEL __

11. RELATED TECHNOLOGY REQUIREMENTS:

DEFINITION OF TECHNOLOGY REQUIREMENT NO.

1. TECHNOLOGY REQUIREMENT (TITLE): Radio Frequency Mass Quantity Gauging

PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Analysis																			
2. Design & FAB																			
3. Ground Test																			
4. Flight Test																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																	TOTAL
TECHNOLOGY NEED DATE																	
NUMBER OF LAUNCHES																	

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

I. Energy Source and Conversion

D. Ambient Field Trapping

No experiments were identified.

II. Power Processing, Distribution, Conversion and Transmission

The present NASA mission payload model refects a series of missions which would benefit from significant increases in the present state-of-the-art in power processing, distribution, conversion and transmission. While it is possible to perform these missions with present technology, severe weight, cost and reliability would result. The suggested technology improvements outlined herein will result in the needed advancements to make these missions more economically/ technically feasible.

A self-aligning multipin electrical connector assembly development is outlined which will permit reliable spacecraft interfacing during shuttle servicing of orbital spacecraft. Both high and low voltage applications of these connector assemblies must be developed to support the projected missions.

Multi-kilowatt load distribution systems, with highly efficient power processing conversion devices, are required for a large series of missions including ion propulsion powered planetary missions. Likewise improvements by a factor of two or more in power system lifetime performance, reliability and weight reduction are necessary to economically support these projected missions. Three programs are outlined which will generate the necessary technological advancements.

Mariner class spacecraft, atmospheric probes, planetary landers and astericd cometary rendezvous spacecraft, will require increased power system operational reliability for extended mission lifetimes. An automated power system management system is suggested employing existing microprocessors and methodology of autonomous operation now under development; lifetimes in excess of 10 years are required.

Development of a long life 10-20KWe unattended power station is required for increased shuttle sortie mission time and payload capability. The technologies required for this development are now in existance (solar array) or development (shuttle fuel cell).

DEFINITION OF TECHNOLOGY REQUIREMENT NO. ____

1. TECHNOLOGY REQUIREMENT (TITLE): Spacecraft Charging and High Voltage Interactions With Plasma PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Electric Power

3. OBJECTIVE/ADVANCEMENT REQUIRED: Determine theory and verify by engineering data to account for interactions of charged surfaces with plasmas.

4. CURRENT STATE OF ART: Discharges of flight spacecraft due to plasmas have been identified which have/may cause failures. Other plasma interactions are being determined experimentally. HAS BEEN CARRIED TO LEVEL ___

5. DESCRIPTION OF TECHNOLOGY

A number of spacecraft have experienced arcs and discharges in flight, some of them endangering the spacecraft. An active program in conjunction with the USAF is underway to obtain engineering data and correlate these data with theory to understand the phenomena. The result will be design criteria to prevent such discharges on future SC. Further, for advanced power concepts such as the High Voltage Solar Array, an understanding must be obtained of the interactions of high voltage (hundreds to thousands of volts) with plasmas.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☒ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. SEPS (PL-23 thru 26) missions currently plan on a 200-400 volt solar array bus; advanced concepts using on-array regulation would use 1100V; CTS and other advanced communications payloads (CN-1,2,4) will deal up to 45KV, SSPS is an ultimate potential user.

TO BE CARRIED TO LEVEL ___

DEFINITION OF TECHNOLOGY REQUIREMENT NO.

1. TECHNOLOGY REQUIREMENT(TITLE): Spacecraft Charging and High Voltage Interactions With Plasma

7. TECHNOLOGY OPTIONS:

Continue ground based tests and attempts to correlate with theory/observed flight data; or obtain flight data specifically for the intended purpose and verify theory/observations.

8. TECHNICAL PROBLEMS:

Ground tests, because of the nature of facilities, provide data which differ by orders of magnitudes.

9. POTENTIAL ALTERNATIVES:

Abandon investigations into charging phenomenon and hope that failures are acceptably few.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

EXPECTED UNPERTURBED LEVEL __

11. RELATED TECHNOLOGY REQUIREMENTS:

DEFINITION OF TECHNOLOGY REQUIREMENT NO.

1. TECHNOLOGY REQUIREMENT (TITLE): Spacecraft Charging and High Voltage Interactions With Plasma

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1.																			
2.																			
3.																			
4.																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																		TOTAL
TECHNOLOGY NEED DATE																		
NUMBER OF LAUNCHES																		

14 REFERENCES:

LeRC Preliminary Plan for Space Plasma High Voltage Interaction Experiment Satellites (SPHINX B/C).
February 28, 1975.

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. C

1. TECHNOLOGY REQUIREMENT (TITLE): Unattended Utility Power Station PAGE 1 OF ___

2. TECHNOLOGY CATEGORY: Electric Power

3. OBJECTIVE/ADVANCEMENT REQUIRED: Development of long life 10-20 KWe, low voltage, unattended power stations for use during extended shuttle sortie missions.

4. CURRENT STATE OF ART: Solar arrays in 10-20 KWe power range are presently available. Shuttle fuel cells in power range are currently under development.

HAS BEEN CARRIED TO LEVEL 4

5. DESCRIPTION OF TECHNOLOGY

A 10-20 KWe, shuttle voltage compatible, solar array- regenerative fuel cell power system is required to support extended shuttle sortie flights without requiring extensive shuttle power capability requirements. The power station should be capable of unattended operation for periods up to 1 year, and periodic shuttle visits for a minimum of 10 years.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☒ C/D

6. RATIONALE AND ANALYSIS:

(a) Technology now in existance, or in development, will permit extended shuttle sortie flights without unduly restricting the length of each flight by requiring the shuttle to carry sufficient power capability on each flight. Excess H_2 & O_2 produced on the power station in regenerative fuel cell system could be removed from the power station for use on the shuttle.

(b) Shuttle

(c) Greater shuttle sortie capability since power capability for entire mission is not required to be carried on each flight by shuttle.

(d) Flight test or extensive ground testing of entire of power station would be required to provide qualification of design.

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT

NO. C

1. **TECHNOLOGY REQUIREMENT(TITLE):** Unattended Utility Power Station

7. **TECHNOLOGY OPTIONS:**

(a) Decreased shuttle sortie mission duration.
(b) Increased load capability of shuttle to permit extended power capability generation.
(c) Use of conventional storage system (e.g. batteries) instead of regenerative fuel cells.

8. **TECHNICAL PROBLEMS:**

(a) Development of self aligning multipin Electrical Connector Assembly (See DTR # A)
(b) Development of long-life, reliable fuel cell system.

9. **POTENTIAL ALTERNATIVES:**

See 7 above.

10. **PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:**

EXPECTED UNPERTURBED LEVEL 5

11. **RELATED TECHNOLOGY REQUIREMENTS:**

NONE

DEFINITION OF TECHNOLOGY REQUIREMENT

NO. C

1. TECHNOLOGY REQUIREMENT (TITLE): Unattended Utility Power Station

PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Develop regenerative fuel cell-electrol. technology																			
2.																			
3. Ground qual of design of power station cept																			
4.																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																		TOTAL
TECHNOLOGY NEED DATE					Δ													
NUMBER OF LAUNCHES																		

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. D

1. TECHNOLOGY REQUIREMENT (TITLE): Automated Power Systems Management (APSM) PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Electric Power

3. OBJECTIVE/ADVANCEMENT REQUIRED: Increased operational reliability for extended missions through automated monitoring, computation, command, and control of power system functions.

4. CURRENT STATE OF ART: Methodology of autonomous operation now under development; microprocessing sensors within present state of the art; lightweight sensors need further development. HAS BEEN CARRIED TO LEVEL 3

5. DESCRIPTION OF TECHNOLOGY

Future planetary spacecraft will have to perform long duration, complex missions with significantly less ground control than their predecessors. System capability will be pressed by the wide variations in power system parameters: long (>10 years lifetimes) duration; increased action/reaction cycle time (up to 8 hours); ability to provide fault correction capability autonomously as real time ground station intervention cannot occur in real time. The proposed APSM system will automatically perform the required monitoring, computational, command and control functions without the need for ground intervention. The APSM technology whould be developed for both solar array/battery and RTG powered spacecraft missions.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

(a) Large earth-spacecraft distances (up to 30 Au at Neptune); lengthening action/reaction time; long duration (up to 10 years); extended communicative black-out periods; unique maneuvering and adaptive mission planning requirement.
(b) Mariner Class Spacecraft, atmosphere probes, planetary landers, asteriod/cometary rendezvous. (e.g. PL-21in 1973 Mission Model)
(c) Ability to quickly respond to changing mission conditions; reduction in time/personnel needed for predicted power system response to mission sequences; increased science data return due to fewer required power system telemetry channels; continuous power system operation with equipment degradation/failure.
(d) Lightweight current/voltage/temperature sensor development required.

TO BE CARRIED TO LEVEL 5

DEFINITION OF TECHNOLOGY REQUIREMENT NO. D

1. TECHNOLOGY REQUIREMENT(TITLE): Automated Power Systems Management (APSM) PAGE 2 OF 3

7. TECHNOLOGY OPTIONS:

Only alternative to APSM is ground-controlled monitoring and operation of the power system with the attendant penalties outlined in Sections 5 & 6.

8. TECHNICAL PROBLEMS:

Development of lightweight, low-loss sensors for monitoring the operation of the power system.

9. POTENTIAL ALTERNATIVES:

See 7 above.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

No planned programs

EXPECTED UNPERTURBED LEVEL 3

11. RELATED TECHNOLOGY REQUIREMENTS:

Future developments in reducing the weight, cost and power loss of spacecraft computers would enhance the application of APSM to Planetary exploration mission.

DEFINITION OF TECHNOLOGY REQUIREMENT NO.

1. TECHNOLOGY REQUIREMENT (TITLE): Automated Power Systems Management (APSM) PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Functional Requirements																			
2. Prel. Design																			
3. Detailed Design																			
4. Fabrication																			
5. Test/Eval.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																	TOTAL
TECHNOLOGY NEED DATE																	
NUMBER OF LAUNCHES																	

14. REFERENCES:

"Plan for the Development of Automated Power Systems Management," Jet Propulsion Laboratory, EM-342-254, 19 June 1974.

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. ______

1. TECHNOLOGY REQUIREMENT (TITLE): Solar Array Power Generation and Management, HVSA

2. TECHNOLOGY CATEGORY: Electric Power

3. OBJECTIVE/ADVANCEMENT REQUIRED: Increase reliability and performance and decrease electrical subsystem weight through multi-kilovolt signal conditioning with circuits that are integral to the solar array.

4. CURRENT STATE OF ART: High voltage array system at voltage 100 V dc levels are well within the state-of-the-art, as typified by the Communications Technology Satellite (Canadian) to be launched in 1975. 400 Vdc is considered an upper limit

HAS BEEN CARRIED TO LEVEL __

5. DESCRIPTION OF TECHNOLOGY

The electronic components (e.g. SCRs) required to perform the necessary switching function between solar cell blocks must be capable of blocking 15 kilovolts in the forward direction. The reliability associated with these devices must be sufficiently high to support missions of 5 to 10 years duration. With the exceptions of the high reliability high-voltage switching devices and compatibility of high voltage surfaces with plasmas, the technology for high voltage solar arrays is available and will improve with the development of high efficiency solar cells. The design of the solar array and its individual components must be able to withstand the high voltage levels (e.g., up to 15 kV) without voltage breakdown. The state-of-the-art is 76V dc on the Canadian Communications Satellite. A laboratory solar array at the Lewis Research Center has been operated at 1500 volts without problems (Reference #3).

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

(a) The 15 kilovolt level for the switching devices is based on the requirements of advanced communication traveling wave tubes as required for the communications R & D prototype satellite (CN-01A).

(b) In addition to payload CN-01A, advanced geosynchronous satellites utilizing ion propulsion will benefit from this technology. The majority of these applications fall in the disciplines of Earth Observation and Communication/Navigation. Further, it is a necessary technology upon which to base major SSPS decisions.

(c) Heavy, complex power conditioning equipment used in low voltage solar array systems significantly reduces the reliability of the system.

(d) This technology advancement should be carried to an experimental demonstration in an automated spacecraft or an early shuttle flight.

TO BE CARRIED TO LEVEL __

DEFINITION OF TECHNOLOGY REQUIREMENT

NO.

1. **TECHNOLOGY REQUIREMENT(TITLE):** Solar Array Power Generation and Management, HVSA

7. **TECHNOLOGY OPTIONS:**

An alternative to the high voltage SCR may be a high voltage electromagnetic vacuum relay of sufficiently small dimensions to permit integral accommodation with the solar array. Solid state control circuits are technology limited. Transistors & SCRs with capabilities beyond a few hundred volts are beyond the state-of-the-art.

8. **TECHNICAL PROBLEMS:**

1. Interaction of array with charged particle environment (Reference #4)
2. High voltage SCRs with high reliability may not be feasible. SCR thermal dissipation on the solar array substrate has presented serious design limitations.
3. The design of the array to prevent voltage breakdown will be difficult in view of the light weight quality of the arrays and the possibility of sharp protrusions and discontinuities producing arcing. Shielding presents significant weight penalties.

9. **POTENTIAL ALTERNATIVES:**

Design using a larger number of lower voltage SCRs is possible.

Design with a higher bus voltage, up to the limit where voltage breakdown may present a hazard with conventional design practice.

10. **PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:**

RTOP 502-24-17 "Solar Array Technology for Solar Electric Propulsion State" could be expanded in scope to also investigate high voltage designs.

EXPECTED UNPERTURBED LEVEL ___

11. **RELATED TECHNOLOGY REQUIREMENTS:**

Electrical power control component technology, high voltage level distribution systems.

DEFINITION OF TECHNOLOGY REQUIREMENT NO.

1. TECHNOLOGY REQUIREMENT (TITLE): Solar Array Power Generation and Management, HVSA

PAGE 3 OF 4

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1.																			
2.																			
3.																			
4.																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

CALENDAR YEAR

13. USAGE SCHEDULE:

																	TOTAL
TECHNOLOGY NEED DATE																	
NUMBER OF LAUNCHES																	

14. REFERENCES:

1. "Study High Voltage Solar Array Configurations with Integrated Power Control Electronics," Final Report, Contract NAS 3-8997, General Electric Company.
2. "High Voltage Solar Array Experiments," Final Report, Contract NAS 3-14364, The Boing Company.
3. "High Voltage Solar Cell Power Generator System," by E. Levy, Jr., R. Opjordan, A. C. Hoffman, 10th IEEE Photovoltaic Specialists Conference.
4. "The Interaction of Spacecraft High Voltage Power Systems with the Space Plasma Environment," by S. Domitz and N. T. Grier, Proceedings of the Power Electronics Specialists Conference, June, 1974.

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. ____

1. TECHNOLOGY REQUIREMENT (TITLE): Solar Array Power Generation and Management, HVSA PAGE 4 OF 4

DEFINITION OF TECHNOLOGY REQUIREMENT NO. E

1. TECHNOLOGY REQUIREMENT (TITLE): Advanced Power Processing/Monitoring System PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Electric Power

3. OBJECTIVE/ADVANCEMENT REQUIRED: Improvements in life, performance, reliability and weight by approximate factors of two; improvements in operational status and reduction in post flight maintenance time and costs.

4. CURRENT STATE OF ART: Preliminary designs of regulation, conversion and monitory techniques involved using advanced analytic methods.

HAS BEEN CARRIED TO LEVEL 4

5. DESCRIPTION OF TECHNOLOGY

Power processing and monitoring components that can operate from widely variable sources for extended lifetime with high reliability are required for both deep space and shuttle missions. Two-fold improvements in current technology are needed to maximize scientific return and enhance cost effectiveness. Improved technology will also permit real time assessment of safety in the event of system degradation/failure. Trend analysis of system performance will decrease the time/cost of on-ground shuttle maintenance. Manual override capabilities will be incorporated in the selected design for shuttle operation.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

(a) Shuttle power system maintenance and analysis effort reduced through use of improved monitoring system; increased shuttle and planetary performance/reliability through two-fold increase in component lifetime, performance and weight reduction.
(b) Shuttle, planetary mission (See 1973 Mission Model "PL")
(c) Greater science return at less cost; better performance reliability, lifetime and lower weight; reduced shuttle power system maintenance effort.
(d) This technology should be advanced to the point of flight qualifications. Ground environment of tests are sufficient to do this.

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 7

1. TECHNOLOGY REQUIREMENT(TITLE): Advanced Power Processing/Monitoring System PAGE 2 OF 3

7. TECHNOLOGY OPTIONS:

Two types of high performance switching regulators are required: one for low voltage (≤ 50 volts) inputs, and one for high voltage (200-400 volts). Each unit features active redundant modules and a high resolution, high speed feedback controller. Time shared on-board computers could be used to evaluate system performance/safety assessment.

8. TECHNICAL PROBLEMS:

1. High voltage switching transistors and storage capacitors.
2. Automatic load sharing between active redundant modules.
3. Automatic fault detection/trend/safety analysis and module disconnection without system interruption.

9. POTENTIAL ALTERNATIVES:

1. Low voltage power distribution techniques would simplify design, at increased power dissipation/weight penalty.
2. Time shared on-board computer for performance analysis.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

RTOP #506-23-33 "Long-life, high performance power.
Processing for planetary applications.
Effort would need to be expanded to consider trend/safety analysis consideration.

EXPECTED UNPERTURBED LEVEL 5

11. RELATED TECHNOLOGY REQUIREMENTS:

1. Improved high voltage semiconductor components and capacitors
2. Microprocessor cost/weight reductors and reliability improvements
3. Energy storage device (e.g. battery) characterizations improvements

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. E

1. TECHNOLOGY REQUIREMENT (TITLE): Advanced Power Processing/Monitoring System — PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Analysis/Design																			
2. Fabrication																			
3. Test																			
4.																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																	TOTAL
TECHNOLOGY NEED DATE				Δ													
NUMBER OF LAUNCHES																	

14. REFERENCES:

1973 NASA Mission Models

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT

NO. ______

1. TECHNOLOGY REQUIREMENT (TITLE): Multi KW, High Voltage Processor and Distribution System for Special Applications — PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Electric Power

3. OBJECTIVE/ADVANCEMENT REQUIRED: Provide and demonstrate the technolgoy to make possible lightweight, high efficiency, low cost power processing and distribution systems of multi KW, multi KV levels for special applications.

4. CURRENT STATE OF ART: Power processing and distribution systems are in various levels of demonstration with output voltages up to 11 KV, output power up to 3KW/unit and efficiencies near 90%.

HAS BEEN CARRIED TO LEVEL 4.5

5. DESCRIPTION OF TECHNOLOGY

Advances must be made in all areas (systems, concepts, circuits, components, materials, thermal control) to properly match the increasing demands of various loads with the variety of available power sources. Loads now in planning have been identified as requiring voltages up to 45KV and powers up to 10KW/unit with 5-10 year lifetimes. Advanced loads need 500 KW at 5KV for 15 years. Input voltages may go up or down while efficiencies must approach the mid to upper nineties range, and the weight per KW reduced by a factor of 5 to 10.

P/L REQUIREMENTS BASED ON: * ☒ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

(a) Advanced travelling wave tubes (CN-1,2,4) will require up to 45 KV and certain solar electric propulsion concepts (PL-23 thru 26) may need near 10KW of power per thruster. Outer planet investigations (PL-15 thru 22 of the 1973 Payload Model) are being considered using Nuclear Electric Propulsion which would demand 500KW and 5KV levels. These are plateaus which must be reached before SSPS, space station and colonization attemps can be feasible.

(b) Payloads using advanced TWTs, such as direct broadcast and disaster warning satellites, and solar and nuclear electric propulsion will benefit from this technology as will other payloads requiring high voltage and/or power.

(c) Presently the technology does not exist to produce lightweight, reliable, efficient, low cost power processing systems for the high power/voltage ranges required.

(d) This technology advancement can be achieved primarily through ground tests. Demonstration/confidence tests may be required at the systems level for user considerations.

TO BE CARRIED TO LEVEL 5

DEFINITION OF TECHNOLOGY REQUIREMENT	NO.

1. **TECHNOLOGY REQUIREMENT(TITLE):** Multi KW, High Voltage Power Processor and Distribution System for Special Applications **PAGE 2 OF 3**

7. **TECHNOLOGY OPTIONS:**

The spectrum of technology encompassed is broad, ranging from improved materials for high voltage/power use, improved electronic components, new design and analytical tools for cost reduction, to improved circuits and new systems concepts.

8. **TECHNICAL PROBLEMS:**

Too numerous to list.

9. **POTENTIAL ALTERNATIVES:**

None.

10. **PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:**

RTOPs 506-23-3

EXPECTED UNPERTURBED LEVEL ___

11. **RELATED TECHNOLOGY REQUIREMENTS:**

Thermal control technology, solar and nuclear power sources TWT and electric thruster technologies.

DEFINITION OF TECHNOLOGY REQUIREMENT NO.

1. TECHNOLOGY REQUIREMENT (TITLE): Multi KW, High Voltage Power Processor and Distribution System for Special Applications PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

SCHEDULE ITEM	CALENDAR YEAR 75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. SEP Development	---	---	---	---	---														
2. NEP Development			---	---	---	---	---	---	---										
3. TWT Development	---	---	---	---	---	---	---												
4.																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																	TOTAL
TECHNOLOGY NEED DATE																	
NUMBER OF LAUNCHES																	

14. REFERENCES:

15. **LEVEL OF STATE OF ART**

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. A

1. TECHNOLOGY REQUIREMENT (TITLE): Self-Aligning Multipin Low/High Voltage Electrical Connector Assembly PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Electric Power - Special Devices

3. OBJECTIVE/ADVANCEMENT REQUIRED: Electrical interface for resupply and refurbishment of orbiting spacecraft employing low/high voltage distribution systems.

4. CURRENT STATE OF ART: Low voltage development hardware has been fabricated; feasibility of low voltage application has been demonstrated.

HAS BEEN CARRIED TO LEVEL 4

5. DESCRIPTION OF TECHNOLOGY

Multipin electrical connectors are required to transverse the spacecraft/module interface of an in orbit serviceable spacecraft. Connector design will permit reliable engagement or interruption of power, data and communication lines when malfunctioning and/or depleted systems are replaced remotely on an orbiting spacecraft. Assemblies capable of being used in both the low (<75 volt) and high (>75 volt) voltage distribution systems are required.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☒ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

(a) The present method for orbiting a spacecraft precludes its recovery for repair and/or refurbishment. The cost effective solution is to provide a Shuttle Tug compatible system to recover, repair and reorbit spacecraft.

(b) EOS-A,B,C, and D; SMM; GRE; SSOS; SEOS; SEASAT will benefit in low voltage application. SSPS/SEPS are potentially benefiting payloads in high voltage application.

(c) In orbit repair and/or refurbishment of spacecraft will replace the present method of operation (launching a second or back-up spacecraft to complete the mission of a malfunctory/deleted spacecraft).

(d) The test of a model of this type of assembly in a spacecraft (GRE) to demonstrate its applicability will satisfy the low voltage technology requirement. A flight experiment of a high voltage assembly must be performed.

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT **NO. A**

1. **TECHNOLOGY REQUIREMENT(TITLE):** Self-Aligning Multipin Low/High Voltage Electrical Connector Assembly **PAGE 2 OF 3**

7. **TECHNOLOGY OPTIONS:**

(a) Develop a connector for refurbishment and/or repair of malfunctioning spacecraft system as described in paragraph No. 5.
(b) Capture and return spacecraft to earth for electrical disconnection.
(c) Continue present mode of operation, i.e., launch a backup spacecraft to replace the one that has malfunctioned.

8. **TECHNICAL PROBLEMS:**

(a) Alignment and mating of up to 200 power, data and communication pins/sockets including an undetermined number of coaxial interfaces.
(b) The effect of thermal gradients on pin/socket alignment.
(c) The effect of high voltage on connector assembly design.
(d) TDRSS compatible-high power with no multipacting.
(e) Connector design must be compatible with megabit data rates.
(f) Connector must have built in verification of proper engagement.

9. **POTENTIAL ALTERNATIVES:**

Aside from those discussed in Section 7, there are no known potential alternatives.

10. **PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:**

GRE Spacecraft for low voltage application.

EXPECTED UNPERTURBED LEVEL ___

11. **RELATED TECHNOLOGY REQUIREMENTS:**

Developing tool to measure pin/socket engagement and disengagement forces.

DEFINITION OF TECHNOLOGY REQUIREMENT	NO.

1. TECHNOLOGY REQUIREMENT (TITLE): Self-Aligning Multipin Low/High Voltage Electrical Connector Assembly

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Design Low Voltage Assembly																			
2. Fab./Mat Low Voltage Assembly																			
3. Design High Voltage Assembly																			
4. Fab./Mat High Volta Voltage Assembly																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	TOTAL
TECHNOLOGY NEED DATE				1 Δ						2 Δ								
NUMBER OF LAUNCHES					2	2	1	2	1	*	1	*	*	1	*	*	*	9

14. REFERENCES:

(a) Flight Support System for Earth Observation Satellites (NASA 5-23203, Mod 4) SD74-SA-005;.

(b) Letter NASA/GSFC File No. 8213, Code 730, Subject: "Study of Future Payload Technology Requirements, Construct NAS2-8272," F. J. Cepollina to H. Ikerd, G. D. Convair, dated 10 January 1975.

(c) "In-Orbit Servicing" - by F. J. Cepollina & J. Mansfield, pages 46-56 Astronautics & Aeronautics, Vol. 13, No. 2, dated February 1975.

* Resupply Units
1. Low Voltage Assembly
2. High Voltage Assembly

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

III. Storage

At present, NiCd batteries are used as the energy storage system for all Low Earth Orbiting (LEO) Payloads that have operating life requirements exceeding 30 to 45 days. There are presently several factors that limit the life capabilities of the NiCd batteries. These factors include the effects operating temperatures have on material stability, life limits of separator materials in the battery electrolyte, useable capacity with voltage degradation, etc.

Two methods have been proposed to meet these life requirements. The first is to upgrade the state-of-the-art of the NiCd battery system including charge control and heat removal. The second approach is to develop and flight qualify the NiH_2 battery system. Both proposals are defined by their respective Technology Development Forms.

There has also been a requirement identified for a high energy density battery for the outer planet probes. The propulsion group has a requirement for a lightweight battery for use with auxiliary thruster for stationkeeping and attitude control. The metal gas cells offer energy density improvements by a factor of 2 over NiCd.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. ______

1. TECHNOLOGY REQUIREMENT (TITLE): NiCd Secondary Battery System for LST PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Electric Power

3. OBJECTIVE/ADVANCEMENT REQUIRED: To improve the life and performance of the battery system thereby reducing the required number of revisits.

4. CURRENT STATE OF ART: Present battery systems will require replacement at approximately 2.5 year intervals.

HAS BEEN CARRIED TO LEVEL 4

5. DESCRIPTION OF TECHNOLOGY

There are several factors that limit the operational life capabilities of NiCd battery systems. These factors include operating temperatures, useable capacity of electrodes after cycling, life limits of separators at operating temperatures, etc. Efforts are under way and should be continued to understand the cause of electrode capacity degradation. The capacity can be restored by proper reconditioning and a flight system to perform this function should be developed. Development of separator materials with longer life capabilities should also be pursued.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☒ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a) Battery life is at present the pacing item in the requirement for revisits of the shuttle for maintenance purposes.
b) LST and any other long life earth orbiting payload using NiCd battery energy storage system will benefit from this program.
c) Justification is primarily to reduce required revisits of shuttle, therefore resulting in a considerable overall saving to the total program.
d) The reconditioning system should be laboratory tested. Any change in separators or electrodes should be life tested in the laboratory.

TO BE CARRIED TO LEVEL 5

DEFINITION OF TECHNOLOGY REQUIREMENT

NO.

1. **TECHNOLOGY REQUIREMENT(TITLE):** NiCd Secondary Battery System for LST **PAGE 2 OF 3**

7. **TECHNOLOGY OPTIONS:**

An option to the NiCd battery system would be one of the metal-gas electrode systems. These systems are in relative early stages of development but should be given strong consideration since they have potential advantages in extending useable life 4-5 times and much simpler change control systems.

8. **TECHNICAL PROBLEMS:**

Prototype reconditioning system has been operated, flight system must be developed. Electrode problems are not completely understood and requires basic analysis. New separator systems must be developed for improvement.

9. **POTENTIAL ALTERNATIVES:** See options above.

The alternative to solving the technical problems is to use present technology and limit operation to the limitations of the system.

10. **PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:**

None planned.

EXPECTED UNPERTURBED LEVEL ___

11. **RELATED TECHNOLOGY REQUIREMENTS:**

None anticipated.

DEFINITION OF TECHNOLOGY REQUIREMENT	NO.

1. TECHNOLOGY REQUIREMENT (TITLE): NiCd Secondary Battery System for LST

PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Battery component analysis		—	—																
2. Reconditioning system development demonstration		—	—																
3. Battery performance demonstration			—	—															
4. Life Confidence Test			—	—	—														
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																	TOTAL
TECHNOLOGY NEED DATE																	
NUMBER OF LAUNCHES																	

14. REFERENCES:

1973 NASA Payload Model June 1973
AST-6

Funding cy$ 76-50 k
77-100k
78-100k
79-50 k
80-50 k

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. ______

1. TECHNOLOGY REQUIREMENT (TITLE): NiH_2 Energy Storage System for Low Earth Orbit, Long Life Payloads, LST PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Electric Power

3. OBJECTIVE/ADVANCEMENT REQUIRED: Longer life and higher performance than available from the present NiCd battery system.

4. CURRENT STATE OF ART: Early stages of battery development. Cell performance characteristics demonstrated.

HAS BEEN CARRIED TO LEVEL 4

5. DESCRIPTION OF TECHNOLOGY

Gas electrode batteries offer promise of improved energy densities, better temperature constraints and excellent rechargeable prospects. Cells have been fabricated and evaluated. Life capabilities of cells and battery systems should be demonstrated.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☒ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a) LST and other payloads requiring long life performance in low earth orbit are presently limited by battery capabilities. Shuttle revisits are placed by battery life.
b) LST and others.
c) NiH_2 system should provide a life of 4 times greater than NiCd while also providing improvements and simplicity in thermal control and changing systems and at least double energy density.
d) Total systems should be demonstrated as to operational capabilities and demonstration of life to exceed that of NiCd system.

TO BE CARRIED TO LEVEL 5

DEFINITION OF TECHNOLOGY REQUIREMENT | NO.

1. TECHNOLOGY REQUIREMENT(TITLE): NiH_2 Energy Storage System for Low Earth Orbit, Long Life Payloads - LST | PAGE 2 OF 3

7. TECHNOLOGY OPTIONS:

The options are to use NiCd battery systems and operate within their capabilities.

8. TECHNICAL PROBLEMS:

Known problems have been analyzed. Capabilities now need to be demonstrated.

9. POTENTIAL ALTERNATIVES:

See options.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Depend on DOD and Consat programs.

EXPECTED UNPERTURBED LEVEL

11. RELATED TECHNOLOGY REQUIREMENTS:

None anticipated.

DEFINITION OF TECHNOLOGY REQUIREMENT	NO.

1. TECHNOLOGY REQUIREMENT (TITLE): NiH_2 Energy Storage for Low Earth Orbit, Long Life Payloads - LST   PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Evaluation of Cell status																			
2. Development of Battery System																			
3. Life Confidence Test Program																			
4.																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE: Depends on Schedules Established

																	TOTAL
TECHNOLOGY NEED DATE																	
NUMBER OF LAUNCHES																	

14. REFERENCES:

The 1973 NASA Payload Model, June 1973.

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. ____

1. TECHNOLOGY REQUIREMENT (TITLE): High Energy Density Batteries. PAGE 1 OF ___

2. TECHNOLOGY CATEGORY: Electric Power

3. OBJECTIVE/ADVANCEMENT REQUIRED: Improvement by factor of 2 over NiCd batteries in energy density. Simpler charge control system.

4. CURRENT STATE OF ART: NiCd cells

HAS BEEN CARRIED TO LEVEL 7

5. DESCRIPTION OF TECHNOLOGY

The metal/gas cell must be qualified in space to meet the requirements of the outer planet probes (PL Series) the propulsion working group has submitted a requirement for cells for use with auxiliary electric thruster stationkeeping and attitude control of geosynchronous satellites.
(EOP, PHY, AST Series)

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☒ C/D

6. RATIONALE AND ANALYSIS:

The metal gas cells offer energy density improvements by at least a factor of 2 over Ni-Cd. In addition the simpler charge control system (overcharge tolerance) affords considerable promise in reliability and control improvements.

The technology advancements should be carried to an experimental demonstration on an early shuttle/COEF flight.

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT NO.

1. TECHNOLOGY REQUIREMENT(TITLE): High Energy Density Batteries

7. TECHNOLOGY OPTIONS:

Continued use of heavier, more complicated nickel-cadmium power systems. High rate silver-zinc cells - not yet qualified by flight test and over-designed to compensate for zero gravity environment.

8. TECHNICAL PROBLEMS:

Availability of electrolyte at catalytic surface of negative electrode during charge. Flooding of catalytic surface of negative electrode during discharge.

9. POTENTIAL ALTERNATIVES:

Over-designed Ag-Zn cells.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

RTOP 506-26-23

EXPECTED UNPERTURBED LEVEL 5

11. RELATED TECHNOLOGY REQUIREMENTS:

Fluid control under zero "g"

DEFINITION OF TECHNOLOGY REQUIREMENT	NO.

1. TECHNOLOGY REQUIREMENT (TITLE): High Energy Density Batte[illegible]es — PAGE 3 OF ___

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR [illegible]AR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	[illegible]	[illegible]	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Analysis/Design		—	—																
2. Fab/Pkg.			—	—															
3. Test				—	—														
4. Flight				—	—														
5. Analysis/Doc.						—	—												
APPLICATION																			
1. Design (Ph. C)						—	—	—											
2. Devl/Fab (Ph. D)							—	—											
3. Operations								—	—	—	—	—	—	—	—	—	—		
4.																			

13. USAGE SCHEDULE:

																		TOTAL
TECHNOLOGY NEED DATE																		
NUMBER OF LAUNCHES					7	8	9	9	5	11	10	10	8	10	9	8	9	113

14. REFERENCES:

1. "Gravitational Effects on Electrochemical Batteries," Meredith, Robert E., Juvinall, Gordon L., and Uchiyama, A. A.; JPL Technical Report 32-1570.

2. "Reduced Gravity Battery Test Program," Final Report, Contract 952121, The General Electric Company.

3. "The Effect of Weightlessness on the Performance of Batteries and Fuel Cells," Eisenberg, Morris Proceedings of the 12th Annual Battery R & D Conference; U.S. Army Signal Lab, 1958.

4. "The Sealed Nickel-Hydrogen Secondary Cells," Giver, Jose, and Dunlop, James D., J. Electrochemical Socicty 122 No. 1, p 4, 1975.

Continued

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT **NO.** ____

1. TECHNOLOGY REQUIREMENT (TITLE): High Energy Density Batteries **PAGE** 4 **OF** ___

14. REFERENCES (Continued)

5. "A Nickel-Hydrogen Secondary Cell for Synchronous Orbit Application," Storkel, J. F., Van Omunering, Swette, L., and Gaines, L. 8th IECEC Conference, 1973 Proceedings, p. 87.

6. "Nickel-Hydrogen Battery System:, Klein, M., and Baker, B. S., 9th IECEC Conference, 1974 Proceedings, p. 118.

7. "Nickel-Hydrogen Battery Development for Synchronous Satellites," Gandel, M. G., Chang, R., and Harsch, W. C. ibid. p. 123.

BOOK III: OPPORTUNITY DRIVEN TECHNOLOGY

I. Energy Sources and Conversion

A. Solar Photovoltaic

The report of the outlook for Space Study, July 1975, conclude that "Intensive technology programs and economic studies in---power generation in space---should be pursued to thoroughly evaluate such concepts relative to ground based solutions." Therefore, a long range technology opportunity is the development of the Satellite Solar Power Station (SSPS). However, fundamental to the economic feasibility of the Satellite Solar Power Station is availability of highly efficient, possibly high temperature, advanced photovoltaic energy converters. These converters can either be used to produce power alone or can be combined with a low-cost solar concentrator. The latter system may be more effective, but will require substantial solar cell cooling capability and/or cells capable of high temperature operation.

Three areas of beneficial technology were identified for the basic photovoltaic devices:

a. III-V compound semiconductor solar cells.
b. Multi-junction, edge-illuminated, silicon solar cell.
c. Electromagnetic wave energy converter (EWEC).

The III-V compound cells offer the possibility of a major breakthrough on increased low temperature efficiency (up to 35% AMO at 20°C) by application of sophisticated but existing technology developed for photocathodes. These cells would consist of several layers of binary and ternary materials and would use two or more series connected p-n junctions. A less involved technology applied to development of the Schottky barrier "AMOS" cell and the AlAs-InGa As Hetero-face cell may lead to less spectacular improvements over the present state-of-the-art AMO efficiency of 15% at 20°C.

The III-V compound semiconductor materials also offer the unique capability of efficient cell operation at temperatures up to 300°C. Work proposed under Technology Requirements (mission driven technology) includes development of AlGaAs-GaAs cells to be 9% efficient at 300°C. Thin goal could exceed 10% at 300°C for $Al_x Ga_{1-x} As$-$Al_y Ga_{1-y} As$ $(x > y)$ Heteroface and Graded Band-Gap cells properly designed for high temperature operation. Another approach to the solar concentrator/solar cell system is the multijunction silicon cell (MJSC) operated at low temperatures (30°C). Thin device has a demonstrated efficiency of 10% AMO for concentrations up to 500 AMO, when properly cooled. Conversely to standard silicon cells, the efficiency of the MJSC increases with increasing concentrations. The new EWEC proposed also offers a potential breakthrough on efficiency at both low and higher temperatures; although the fabrication technology is quite sophisticated.

DEFINITION OF TECHNOLOGY REQUIREMENT

NO. ______

1. TECHNOLOGY REQUIREMENT (TITLE): Solar Cell Array for SSPS — PAGE 1 OF ___

2. TECHNOLOGY CATEGORY: Electric Power

3. OBJECTIVE/ADVANCEMENT REQUIRED: Development of very large, very lightweight, inexpensive, high voltage solar cell array.

4. CURRENT STATE OF ART: ______

HAS BEEN CARRIED TO LEVEL ___

5. DESCRIPTION OF TECHNOLOGY

	SSPS Requirement	Current state of art
Area	25 sp. km.	100 sq m
weight/power	1 kg/kw	15 kg/kw
cost	$200/kw	$300,000/kw
voltage	20,000V	70V

P/L REQUIREMENTS BASED ON: ☒ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. SSPS concept and feasibility studies indicate that for efficient power generation and microwave transmissions the array power level must be about 5 Giga W. at 50 KV. SSPS economically competitive with terrestrial power systems, the array must be inexpensive and lightweight to reduce transportation costs.
b. SSPS and large space bases or colonies
c. SSPS will not be practical without the advancement
d. Level of technology maturity required: 7

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT

NO.

1. TECHNOLOGY REQUIREMENT(TITLE): Solar Cell Array for SSPS

7. TECHNOLOGY OPTIONS:

If cost, weight, life or size not achieved, solar cells will not be practical for SSPS.

8. TECHNICAL PROBLEMS:

a. Solar cells with efficiency near theoretical limit
b. Fabrication and handling of very thin cells and arrays
c. Long life array materials (substrate, encapsulant or cover)
d. Radiation damage prevention
e. Large lightweight concentration
f. Development of low cost methods for frontier technology

9. POTENTIAL ALTERNATIVES:

Other power generation systems, such as solar dynamic or nuclear dynamic or thermionic, would have to be developed to meet comparable requirements.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

EXPECTED UNPERTURBED LEVEL 4 or 5

11. RELATED TECHNOLOGY REQUIREMENTS:

Very low cost space transportation system to geosynchronous orbit. Materials and design concepts for large, ultralight space structures. Assembly, attitude control, and sun tracking for large ultralight structures.
Efficient microwave generators.
Large phased microwave array.
RF/DC converters.

DEFINITION OF TECHNOLOGY REQUIREMENT	NO.

1. TECHNOLOGY REQUIREMENT (TITLE): Solar Cell Array for SSPS — PAGE 3 OF ___

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1.																			
2.																			
3.																			
4.																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																	TOTAL
TECHNOLOGY NEED DATE																	
NUMBER OF LAUNCHES																	

14. REFERENCES:

Report of the Outlook for Space Study, July 1975.

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. ______

1. TECHNOLOGY REQUIREMENT (TITLE): High Efficiency, Radiation Resistant, High Temperature, Light Weight III-V Compound Solar Cells PAGE 1 OF ___

2. TECHNOLOGY CATEGORY: Electric Power

3. OBJECTIVE/ADVANCEMENT REQUIRED: Increase initial and end-of-life power conversion efficiencies (η_I and η_{EOL}, respectively) of solar cells to η_I = 20% and η_{EOL} = 19%.

4. CURRENT STATE OF ART: η_I = 15% AMO and η_{EOL} = 11.5% for present laboratory silicon cells and η_I = 14.7% AMO for the best laboratory GaAs Heteroface cells.

HAS BEEN CARRIED TO LEVEL 4

5. DESCRIPTION OF TECHNOLOGY

The required new technology is to increase η_I to 20% and η_{EOL} to 19% by one or more of the following efforts pursued using AlGaAs-GaAs, AlAs-InGaAs, and other III-V material systems:

a. Heteroface cells.
b. Single and double Graded Band-Gap Cells.
c. Schottky-Barrier, Multi-junction cells.

In this area, III V compound semiconductor material are combined with ideas which are combined with ideas which are either novel or are older, but prime for development using new material technology and capability. For example, preliminary evidence indicates that a new class of AlAs-$In_{.09}Ga_{.91}$ cells will provide higher power conversion efficiencies than present $Al_{.8}Ga_{.2}As$-GaAs cells when (Continued)

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. Improved η_I and η_{EOL} will significantly decrease the number of cells needed to achieve specified power requirements, and therefore will increase power to weight ratios for future solar cell arrays. A new high temperature capability will facilitate both use of concentrators with photovoltaic systems and near-sun/high radiation missions.
b. Missions requiring solar electric power, particularly near-sun/high radiation missions and missions requiring solar concentration, e.g. SSPS.
c. Advancement will decrease weight and maintain power output of future solar cell arrays. Also, a new capability of array operation up to 300°C is possible along with increased reliability, particularly in space radiation environments.
d. Simplified material growth and device processing technique amenable to high volume production need to be developed.

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT NO.

1. **TECHNOLOGY REQUIREMENT(TITLE):** High Efficiency, Radiation Resistant, High Temperature, Light Weight III-V Compound Solar Cells **PAGE 2 OF**

7. **TECHNOLOGY OPTIONS:**

Power Systems utilizing cells of reduced η_I and η_{EOL} will require more cells to supply required power. Reduction of η_{EOL} will reduce system reliability in space radiation environment.

8. **TECHNICAL PROBLEMS:**

a. Growing thin layers of III-V material of both uniform and graded composition material.
b. Surface passivation.
c. Maintaining simplicity of processing techniques.

9. **POTENTIAL ALTERNATIVES:**

Si Solar Cells

10. **PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:**

RTOPs 506-18-21
506-16-13

EXPECTED UNPERTURBED LEVEL 4

11. **RELATED TECHNOLOGY REQUIREMENTS:**

None

DEFINITION OF TECHNOLOGY REQUIREMENT	NO.

1. TECHNOLOGY REQUIREMENT (TITLE): High Efficiency Radiation Resistant, High Temperature, Light Weight III-V Compound Solar Cells — PAGE 3 OF ___

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1.																			
2.																			
3.																			
4.																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

CALENDAR YEAR

13. USAGE SCHEDULE:

																	TOTAL
TECHNOLOGY NEED DATE																	
NUMBER OF LAUNCHES																	

14. REFERENCES:

"Outlook for Space" document

"High Efficiency Graded Band-Gap $Al_xGa_{1-x}As$-GaAs Solar Cell," by J. A. Hutchby, Applied Phys. Letters 26, 457 (1975).

"High Efficiency Graded Band-Gap $Al_xGa_{1-x}As$-GaAs p-on-n Solar Cells," by J. A. Hutchby, 11th Photovoltaic Specialists Conference (1975).

"$Ga_{1-x}Al_xAs$-GaAs P-P-N Heterojunction Solar Cells," by H. J. Hovel and J. M. Woodall, J. Electrochem. Soc. 120, 1246 (1973).

"15% Efficient, Anti-Reflection Coated Metal-Oxide-Semiconductor Solar Cell," by R. J. Stirn and Y.C.N.Yeh, Applied Phys. Letters 27, 95 (1975).

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT **NO.** ______

1. TECHNOLOGY REQUIREMENT (TITLE): High Efficiency Radiation Resistant, High Temperature, Light Weight III-V Compound Solar Cells **PAGE** ___ **OF** ___

5. DESCRIPTION OF TECHNOLOGY (Continued)

fabricated using the Heteroface Structure. This is due to the better match between the absorption band of $In_{.09}Ga_{.91}As$ and the solar energy spectral distribution. In another example, the Schottky barrier solar cell by itself is well known and generally suffers from low open circuit voltage. However, MOS theory and technology indicates that a properly fabricated imperfect or "lossy" surface can be used to provide significant improvement in the voltage. This improved voltage, combined with the high short circuit current delivered by GaAs Schottky barrier cells, may provide an improved class of solar cells based on a relatively simple technology. As a last example, technology recently developed for fabricating new III-V photocathodes can now be used to fabricate new solar cells consisting of several layers of different III-V binary and ternary materials combined with two or more p-n junctions. The maximum practical efficiency possible with this structure appears to be in excess of 24% AMO (a maximum of 35% AMO may be possible).

DEFINITION OF TECHNOLOGY REQUIREMENT NO. ______

1. TECHNOLOGY REQUIREMENT (TITLE): Multi-Junction, Edge-illuminated, Silicon Solar Cell PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Electric Power

3. OBJECTIVE/ADVANCEMENT REQUIRED: Improve performance characteristics while optimizing the physical configuration of the cell for exposures in the range of 1 to 1000 AMO.

4. CURRENT STATE OF ART: 16 and 96 Series Connected p+-n-n+ junction cells have been developed through technology feasibility demonstration.

HAS BEEN CARRIED TO LEVEL 4

5. DESCRIPTION OF TECHNOLOGY

The multi-junction, edge-illuminated silicon solar cell (MJSC) is an integrally bonded, sandwich stack of series connected p+-n-n+ unit cells assembled to produce a relatively high voltage (36V) and low current (1ma) solar cell.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. The MJSC has the potential of efficient operation under concentrated sunlight of several solar constants, provided excess heat is removed from the cell. Since concentrators appear to be cheaper than solar cells, this technology could be used on the SSPS.
b. SSPS and possibly SEPS (Solar Electric Propulsion System)
c. Use of the MJSC could provide efficient (approx. 10% AMO) cells for use on SSPS.
d. Should be carried to level 7.

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT | NO.

1. **TECHNOLOGY REQUIREMENT(TITLE):** Multi-junction, Edge-illuminated, Silicon Solar Cell | **PAGE 2 OF**

7. **TECHNOLOGY OPTIONS:**

As cell efficiency decreases, particularly when used in a concentrator system, the specific mass of the array increases which in turn increases the array fabrication and launch cost.

8. **TECHNICAL PROBLEMS:**

a. Additional experimental, analytical, and device optimization work is required.
b. Techniques required to passivate the exposed surface and to provide an anti-reflection coating need to be developed.

9. **POTENTIAL ALTERNATIVES:**

Standard Silicon Cells

10. **PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:**

None

EXPECTED UNPERTURBED LEVEL ___

11. **RELATED TECHNOLOGY REQUIREMENTS:**

Concentrator Technology.

Thermal dissipation technology.

DEFINITION OF TECHNOLOGY REQUIREMENT	NO.

1. TECHNOLOGY REQUIREMENT (TITLE): Multi-junction, Edge-illuminated, Silicon Solar Cell PAGE 3 OF ___

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1.																			
2.																			
3.																			
4.																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																	TOTAL
TECHNOLOGY NEED DATE																	
NUMBER OF LAUNCHES																	

14. REFERENCES:

"Multi-junction, edge-illuminated Solar Cell;" by B. L. Sater, H. W. Brandhorst, T. J. Riley, and R. E. Hart, NASA TMX-71718 (1975).

"High Intensity Solar Cell - Key to Low Cost Photovoltaic Power," by B. L. Sater, C. Gordia, NASA TMX-71718 (1975).

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. ____

1. TECHNOLOGY REQUIREMENT (TITLE): High Efficiency, Low Cost, Radiation Resistant Electromagnetic Wave Energy Converter (EWEC) PAGE 1 OF ___

2. TECHNOLOGY CATEGORY: Electric Power

3. OBJECTIVE/ADVANCEMENT REQUIRED: Increase Efficiency, increase radiation resistance, and reduce cost of converting solar energy to electrical power by using a new dipole antenna/diode detector concept.

4. CURRENT STATE OF ART: Initial efficiency of laboratory Si Solar Cells is 15% AMO, and the end-of-life efficiency is 11.5%.

HAS BEEN CARRIED TO LEVEL ___

5. DESCRIPTION OF TECHNOLOGY

Solar electromagnetic wave energy is converted to electrical power or thermal energy using an array of small dipole antennas matched ot the wavelength spectrum of the sun, coupled with high frequency diode detectors. The maximum theoretical efficiency is not yet known, but may be in excess of 24%.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. Improved initial and end-of-life efficiencies and decreased weight will significantly reduce the overall weight required to achieve specified power requirements. Also, cost of future solar electric power systems could be reduced.
b. Missions requiring solar derived electrical power, e.g. SEPS and SSPS.
c. Advancement will decrease weight and cost while maintaining power output of future space power systems. Also, reliability of future arrays may be increased, particularly in space radiation environments.

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT NO.

1. TECHNOLOGY REQUIREMENT(TITLE): (EWEC) PAGE 2 OF

7. TECHNOLOGY OPTIONS:

Power systems utilizing cells of reduced efficiency will require additional weight to maintain power level. Also increased cost will make them less attractive for either SEPS or SSPS.

8. TECHNICAL PROBLEMS:

a. General problem of identifying low cost and high reliability material and technology for fabricating small dipole antennas on appropriate substates.
b. Development of extremely high frequency dioder.

9. POTENTIAL ALTERNATIVES:

Si and III-V Compound Solar Cells.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Solar Cells

EXPECTED UNPERTURBED LEVEL

11. RELATED TECHNOLOGY REQUIREMENTS:

Planned Unperturbed Level is 1.

I. Energy Sources and Conversion

B. Solar and Nuclear Thermo Electric (Heat Source Technology)

There are many energy sources available for space power systems. Solar concentrator and nuclear heat source technologies are included because they provide for long life, cover the entire power range envisioned and can provide high power densities. In certain missions, there is a need to provide power outside the useful range of solar energy or which requires electric propulsion and high power densities. Nuclear heat sources may be the only heat source capable of meeting mission requirements. Isotope heat sources such as the multi-hundred watt heat source which could be used with thermoelectrics, thermionics, or the dynamic energy conversion systems is included as a nuclear heat source.

The objective of these technologies is to develop heat sources which satisfy the entire power range needs and is adaptable to any power conversion system. A lofty goal of the nuclear heat source technology is the development of an all purpose reactor capable of scaling to all power level needs and adaptable to any power conversion system.

DEFINITION OF TECHNOLOGY REQUIREMENT

NO. ______

1. TECHNOLOGY REQUIREMENT (TITLE): Solar Concentrators for High Temperature Energy Conversion to Electric Power

PAGE 1 OF 4

2. TECHNOLOGY CATEGORY: Electric Power

3. OBJECTIVE/ADVANCEMENT REQUIRED: Develop technology for solar concentrators for small (10-300 Kwt), intermidiate (1000-2500 Kwt) and MW class power systems.

4. CURRENT STATE OF ART: Minimal concentrator technology at low power. No technology available at large power levels.

HAS BEEN CARRIED TO LEVEL 4

5. DESCRIPTION OF TECHNOLOGY

There are many potential applications of solar energy in space which range from low powers (usually photovoltaic) to intermediate such as solar electric propulsion to very high powers in the MW class which may be used to beam energy back to earth via microwave transmission. This technology is unavailable at large levels. This effort should provide the following--

a. Define pointing requirements
b. Develop fabrication methods for low cost lightweight concentrators
c. Develop methods for pointing and stabilizing large concentrators
d. Select and develop materials to meet large, low cost concentrators
e. Ground test to determine performance of concentrator.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. Solar concentration will permit the efficient conversion of solar energy to electric power by providing thermal energy at temperatures useful in thermionic, Brayton or Rankine conversion systems. Concentration ratios in the range of 1000-3000 are required. Accurate pointing and stability of the platform are also required.
b. Solar electric power and propulsion may enter a number of important missions post 1985 such as propulsion for missions in near sun orbit, disposal of hazardous nuclear material into the sun, large space station power and lunar base power.
c. Advanced energy conversion systems will permit high system efficiencies (20-35% + depending on conversion system selected), resulting in substantial reduction in size and weight of collector area as compared to photovoltaic. Substantial cost reductions are also expected.
d. Testing of suitably scaled concentrator in space to demonstrate capability to point and stabilize large structures is required for user acceptance.

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT NO.

1. TECHNOLOGY REQUIREMENT(TITLE): Solar Concentrators for High Temperature Energy Conversion to Electric Power

PAGE 2 OF 4

7. TECHNOLOGY OPTIONS:

Capability to point and stabilize large structure (concentrator) could affect performance. Trade of pointing accuracy versus performance is possible. Fabrication of low cost, high quality mirrors is required.

8. TECHNICAL PROBLEMS:

a. Fabrication of low cost, lightweight concentrators.
b. Pointing and stabilizing large structures.

9. POTENTIAL ALTERNATIVES:

Nuclear heat source.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Unperturbed technology will result in zero capability for intermediate and large powers and limited capability at low power.

EXPECTED UNPERTURBED LEVEL 3

11. RELATED TECHNOLOGY REQUIREMENTS:

Advanced conversion systems (Brayton, Rankine, Thermionic)
Large structures
Pointing and Stabilization

DEFINITION OF TECHNOLOGY REQUIREMENT NO.

1. TECHNOLOGY REQUIREMENT (TITLE): Solar Concentrators for High Temperature Energy Conversion to Electric Power PAGE 3 OF 4

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Analysis/Design			---	---															
2. Fabrication					---	---													
3. Ground Test						--	-												
4. Flight Design & Fab.							---	---											
5. Space Demonstration								--	--										
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

TECHNOLOGY NEED DATE																	TOTAL
NUMBER OF LAUNCHES																	

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. ______

1. TECHNOLOGY REQUIREMENT (TITLE): Nuclear Electric Power for Propulsion or Large Power Uses PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Electric Power

3. OBJECTIVE/ADVANCEMENT REQUIRED: Develop a nuclear heat source adaptable to various conversion systems at various power levels.

4. CURRENT STATE OF ART: Conceptual designs of various systems. Ground testing of ZrH reactor accomplished, Various fast reactor concepts studied.

HAS BEEN CARRIED TO LEVEL 4

5. DESCRIPTION OF TECHNOLOGY

The nuclear heat source is a costly development item. A reactor which can be scaled to any power level and is adaptable to any power conversion system would be ideal. Utilization of heat pipes to transfer heat from the reactor to the working fluid of the power conversion system would separate the reactor from the conversion system. Most reactors are readily scaled in power. Size limits may result from control requirements.

A number of candidate concepts are being investigated. These include the gaseous core fast reactor, a UO_2/Mo cermet fueled fast reactor, and a UN-Li cooled fast reactor. The best reactor concept must be selected to serve as many uses as possible. This technology effort should provide the following:

a. Continue technology development of promising concepts.
b. Evaluate technology and select most promising approach
c. Demonstrate capability on ground test.
d. Demonstrate flight capability in selected experiment.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. The nuclear heat source selected must be capable of operating at temperatures up to 1800°K (thermionics) and power levels of 100 KWe to Mwe. Conversion efficiencies vary from a high of 35% (Brayton) to a low of 18% for thermionics.
b. Nuclear electric power and propulsion may enter a number of missions post 1990 such as lunar base power, exploration of distant planets, etc.
c. Power density of nuclear reactor systems and specific impulse attainable can only be accomplished in this manner for certain missions.
d. Testing of a suitable reactor experiment in space to demonstrate performance and capability is required for user acceptance.

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT **NO.**

1. **TECHNOLOGY REQUIREMENT(TITLE):** Nuclear Electric Power for Propulsion and Large Power Users **PAGE 2 OF 3**

7. **TECHNOLOGY OPTIONS:**

The approach of a universal heat source is primarily accommodated by the use of heat pipes. Certain energy conversion systems such as Brayton may not require this element. This reactor technology is applicable to a wide range of power levels and is essentially independent of the energy conversion system.

8. **TECHNICAL PROBLEMS:**

a. Long life, reliable fuel elements.
b. Reactor fuel-heat pipe bonding
c. Possible venting of fission products to attain long life
d. Long term materials comparibility
e. Neutronics and control

9. **POTENTIAL ALTERNATIVES:**

No known alternatives to high power density and high specific impulse attainable with nuclear electric propulsion for exploration of remote planets.

10. **PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:**

Advancement required will not occur without special effort by NASA.

EXPECTED UNPERTURBED LEVEL 4

11. **RELATED TECHNOLOGY REQUIREMENTS:**

Heat Pipe Technology
Brayton Materials
Rankine Large Radiators (Structures)
Thermionic

DEFINITION OF TECHNOLOGY REQUIREMENT NO.

1. TECHNOLOGY REQUIREMENT (TITLE): Nuclear Electric Power for Propulsion and Large Power Users

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Analysis/Design																			
2. Fabrication																			
3. Test																			
4. Documentation																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																	TOTAL
TECHNOLOGY NEED DATE																	
NUMBER OF LAUNCHES																	

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

I. Energy Sources and Conversion

B. Solar and Nuclear Thermal Electric (Energy Conversion Technology)

There are a number of dynamic and static energy conversion systems which should be evaluated for future use. The dynamic systems include Brayton, Rankine and Stirling and static systems which include thermionic, thermoelectric and dielectric systems. All conversion systems except for the dielectric system are adaptable to either solar or nuclear heat source. The overall objective of the energy conversion technologies is to determine the conversion system or systems best suited to accomplishing mission and opportunity goals. A lofty goal for the energy conversion technologies would be to converge on and develop on all purpose conversion system adaptable to either a solar or nuclear heat source and scalable to all power ranges.

The dynamic conversion systems tend to have higher efficiencies and lower specific weight systems. However, they have not demonstrated reliability in space and exhibit a single point failure mode characteristic.

The static conversion systems tend to have lower efficiencies and higher specific weights. In general, they are considered to offer greater reliability through use of redundant power circuits. Thermonic conversion does have the potential for efficiencies equal to Brayton systems.

The dielectric conversion system has the potential for the highest power density of any conversion system.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. ____

1. TECHNOLOGY REQUIREMENT (TITLE): Extra Terrestrial Brayton Energy Conversion (Solar and Nuclear Heat Source) PAGE 1 OF 4

2. TECHNOLOGY CATEGORY: Electric Power

3. OBJECTIVE/ADVANCEMENT REQUIRED: Development of long life, reliable, efficient and low cost Brayton power systems for various power levels and applications.

4. CURRENT STATE OF ART: Technology for 2-15 KWe power ground demonstrated to 20,000 Hrs. Ground demonstration of 1 KWe Brayton isotope power system planned for 1977. HAS BEEN CARRIED TO LEVEL 5

5. DESCRIPTION OF TECHNOLOGY

The concept of using extra terrestrial energy on earth requires that solar energy be converted into high voltage, direct current power for microwave transmission to rectennas on earth. A Brayton thermomechanical conversion system has the potential to provide suitable power at high efficiency (35-40%).

Certain missions such as near sun orbits, disposal of hazardous nuclear material exploration of distant planets, etc. require high specific impulse thrusters. Solar or nuclear electric propulsion are candidate systems. High voltage direct current power is required.

Low Power systems (1-25KWe) are also served by this technology.

This technology should provide the following for three power ranges, 1-25 KWe, 100-500 KWe and the MWe class. (Continued)

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. A 20 kv potential is required for the amplitron microwave generator if 90% efficiency is to be obtained in the transmission system. Several kv may be required for electric propulsion. The usual voltages would be required for low power systems.
b. Payloads which will benefit from this activity include future experimental space power station laboratories, full sized solar power stations, lunar bases, missions to the sun or distant planets requiring high specific impulse and special applications of low power systems.
c. The high system efficiency will reduce area of collector, size and weight of structure (compared to photovoltaic) and cost of system.
d. Brayton power system must be tested in space for extended periods of time to demonstrate reliability and capability.

TO BE CARRIED TO LEVEL ____

DEFINITION OF TECHNOLOGY REQUIREMENT NO.

1. **TECHNOLOGY REQUIREMENT(TITLE):** Extra Terrestrial Brayton Energy Conversion (Solar and Nuclear Heat Source)

7. **TECHNOLOGY OPTIONS:**

System performance directly affects collector area and weight. Thirty year life may not be attainable. Temperature, performance, life trades will permit selection of optimum system. Advancement of materials technology may provide full life of system. May replace turbomachinery loop at periodic intervals.

8. **TECHNICAL PROBLEMS:**

1. Thirty year reliable life.
2. Single point failure mode (loss of working fluid) demands high containment reliability.
3. Requires good pointing accuracy of concentrator (.05-0.1 deg.).

9. **POTENTIAL ALTERNATIVES:**

Alternatives are photovoltaic, rankine or thermionic conversion systems. All alternatives suffer lower efficiencies and higher collector areas.

10. **PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:**

Unperturbed technology will result in zero capability in large and intermediate systems and partial capability in small systems.

Low Power
High Power

EXPECTED UNPERTURBED LEVEL 5

11. **RELATED TECHNOLOGY REQUIREMENTS:**

Materials
Controls
Concentrators (mirrors)
Large Structures
Nuclear Heat Source

DEFINITION OF TECHNOLOGY REQUIREMENT — NO.

1. TECHNOLOGY REQUIREMENT (TITLE): Extra Terrestrial Brayton Energy Conversion (Solar and Nuclear Heat Source) — PAGE 3 OF 4

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Design																			
2. Fabrication																			
3. Ground Test																			
4. Design Flight Sys.																			
5. Flight Demo Test																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																		TOTAL
TECHNOLOGY NEED DATE																		
NUMBER OF LAUNCHES																		

14. REFERENCES:

RTOP 506-23-4

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. ______

1. TECHNOLOGY REQUIREMENT (TITLE): Extra Terrestrial Brayton Energy Conversion (Solar and Nuclear Heat Source) PAGE 4 OF 4

5. DESCRIPTION OF TECHNOLOGY (Continued)

a. Develop designs that are lightweight and reliable.
b. Identify materials requirements and qualify.
c. Demonstrate performance and life capability via ground test.
d. If warranted, demonstrate space capability of selected size.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. ______

1. TECHNOLOGY REQUIREMENT (TITLE): Extra Terrestrial Rankine Energy Conversion (Solar and Nuclear Heat Source) PAGE 1 OF 4

2. TECHNOLOGY CATEGORY: Electric Power

3. OBJECTIVE/ADVANCEMENT REQUIRED: Development of long life, efficient reliable Rankine power systems of various power levels.

4. CURRENT STATE OF ART: Technology for small, liquid metal, Rankine power systems partically developed. No technology for large Rankine space power systems exists. Low Power / High Power HAS BEEN CARRIED TO LEVEL 5

5. DESCRIPTION OF TECHNOLOGY The concept of using extra terrestrial energy on earth requires that solar energy be converted into high voltage, direct current power for microwave transmission to rectennas on earth. A Rankine thermo-mechanical conversion system has the potential to provide suitable power at high efficiency (~30%).

Certain missions such as near sun orbits, disposal of hazardous nuclear material etc. require high specific impulse thruster. Solar electric propulsion is a candidate system. High voltage direct current power is required. A solar Rankine power system has the potential to provide this power efficiently. Low power systems in the range of 1-25 KWe may also be served by this technology.

This technology should provide the following for three power ranges, namely, 1-25 KWe 100-500 KWe and the MW class.

a. Develop designs that are lightweight and reliable.
b. Demonstrate performance and life capability via ground test.
c. If warranted, demonstrate space capability of selected size.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. Many possible applications exist for this technology over a power range from 1 KWe to more than MWe.
b. Provides opportunity driven capability for meeting many mission needs.
c. Good system efficiency will reduce area of collector size, size and weight of structure (compared to photovoltaic) and cost of system.
d. Rankine power system must be tested in space for extended periods to demonstrate reliability and capability.

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT NO.

1. **TECHNOLOGY REQUIREMENT(TITLE):** Extra Terrestrial Rankine Energy Conversion (Solar and Nuclear) **PAGE 2 OF 4**

7. **TECHNOLOGY OPTIONS:**

System performance directly affects system size and weight. Temperature, performance, life-trades will permit selection of optimum system. Advancement of materials may alleviate weight penalties.

8. **TECHNICAL PROBLEMS:**

1. Two phase flow in zero gravity.
2. Startup of two phase flow system.
3. Single point failure mode (loss of working fluid)
4. Requires good pointing accuracy.

9. **POTENTIAL ALTERNATIVES:**

Alternatives to the solar Rankine power system are photovoltaics, Brayton and thermionic conversion systems. The Rankine system is a near competitor to Brayton and should have higher efficiencies and lower collector areas than photovoltaics or thermionics.

10. **PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:**

Unperturbed technology will provide zero capability at the intermediate (100-500 KWe) and high (> MWC) power levels.

Low Power 5

High Power **EXPECTED UNPERTURBED LEVEL** 0

11. **RELATED TECHNOLOGY REQUIREMENTS:**

Materials
Controls
Concentrators (mirrors)
Large Structures (Radiators)
Nuclear Heat Source

DEFINITION OF TECHNOLOGY REQUIREMENT NO.

1. TECHNOLOGY REQUIREMENT (TITLE): Extra Terrestrial Rankine Energy Conversion (Solar and Nuclear) PAGE 3 OF 4

12. TECHNOLOGY REQUIREMENTS SCHEDULE: Opportunity Driven

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. System Studies																			
2. Design																			
3. Fabrication																			
4. Test																			
5. Documentation																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																	TOTAL
TECHNOLOGY NEED DATE																	
NUMBER OF LAUNCHES																	

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT — NO. ______

1. TECHNOLOGY REQUIREMENT (TITLE): Extra Terrestrial Stirling Energy Conversion (Solar and Nuclear Heat Sources) — PAGE 1 OF 4

2. TECHNOLOGY CATEGORY: Electric Power

3. OBJECTIVE/ADVANCEMENT REQUIRED: Development of reliable, long life, efficient and low cost stirling power systems for low powers.

4. CURRENT STATE OF ART: No technology currently exists for Stirling space power systems.

HAS BEEN CARRIED TO LEVEL 0

5. DESCRIPTION OF TECHNOLOGY The Stirling energy conversion system when combined with a linear generator has the capability of high efficiency at low power levels. This could reduce cost of present Radioisotope Thermoelectric Generators used on various missions by reducing inventory of radioisotope fuel. This technology effort should provide--

a. Design of typical systems and components at power levels of 0.2 and 20 KWe.
b. Identification of materials and other key R & T problem areas.
c. R & T on materials, seals, valving, quality of power output from linear generator; lifetime, reliability.
d. Ground testing of complete systems to determine performance and lifetime capability.
e. If warranted, demonstrate space capability of system at selected power level.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. High efficiency at low power levels may result in reduced cost power systems.
b. Payloads which may benefit from this activity are special low power applications such as RTG's.
c. The high system efficiency will reduce weight and cost of low power systems.
d. Stirling power system must be tested in space for extended periods for user acceptability.

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT — NO.

1. TECHNOLOGY REQUIREMENT(TITLE): Extra Terrestrial Stirling Energy Conversion (Solar and Nuclear Heat Sources) — PAGE 2 OF 4

7. TECHNOLOGY OPTIONS:

Performance (efficiency) will directly affect size and weight of concentrator.

8. TECHNICAL PROBLEMS:

a. Seal life

9. POTENTIAL ALTERNATIVES:

Alternatives are photovoltaic, Brayton, Rankine, thermionic and thermoelectric conversion systems. Photovoltaic and thermoelectric systems suffer lower efficiencies as well as Brayton and Rankine at very low power levels (100-200 WE).

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

No planned program presently exists.

EXPECTED UNPERTURBED LEVEL 0

11. RELATED TECHNOLOGY REQUIREMENTS:

Materials
Structures
Controls
Concentrators (mirrors)
Nuclear Heat Source

DEFINITION OF TECHNOLOGY REQUIREMENT NO.

1. TECHNOLOGY REQUIREMENT (TITLE): Extra Terrestrial Stirling Energy Conversion (Solar and Nuclear Heat Sources)

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Analysis/Design																			
2. Fabrication																			
3. Test																			
4. Documentation																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																	TOTAL
TECHNOLOGY NEED DATE																	
NUMBER OF LAUNCHES																	

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT

NO. ______

1. TECHNOLOGY REQUIREMENT (TITLE): High-Performance Thermionic Conversion

PAGE 1 OF ___

2. TECHNOLOGY CATEGORY: Electric Power

3. OBJECTIVE/ADVANCEMENT REQUIRED: Acquire the technology for economical, durable, high-efficiency thermionic conversion of heat from various energy sources to electric power for use in a wide range of applications.

4. CURRENT STATE OF ART: Thermionic Converters made of refractory metals for in-core nuclear service develop efficiencies between 10 and 15 percent.

HAS BEEN CARRIED TO LEVEL ___

5. DESCRIPTION OF TECHNOLOGY

Substantial converter-component gains are possible because out-of-core thermionics allows material and design freedoms forbidden by in-core nucleonics. New configurations to enhance interelectrode ionization should reduce plasma losses by about 0.5 volt. Such arc drop reductions generally involve significant decreases in cesium pressures and enabled several-fold increases in interelectrode spacings. Even with much lower cesium pressures, promising new emitter materials with bare work functions near 2rV should yield good emission. New collector materials should result in cesiated work functions of approximately 1GV. Overall gains of successful integration of these improved components can affect a change of thermionic-conversion efficiencies from the present 10-to-15 percent to over 30 percent.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. Thermionic conversion is especially valuable for nuclear electric power and propulsion systems because of its capability for handling large power densities and its high temperance for reception and rejection of heat. The nuclear electric power and propulsion systems generally range above the 100kWe level. But thermionic converters can accept heat from any high-temperature energy source like isotopes or concentrated solar energy.

b. Nuclear electric propulsion and power systems should enter a number of important missions beginning in the 1990's: 1) planetary propulsion, 2) earth-orbit propulsion, 3) nuclear-waste disposal propulsion, 4) large-space-station power, and 5) lunar-base power.

c. Advanced thermionic conversion will allow higher efficiencies of lower temperatures, more economical converters with longer lives, and small space radiators than those for in-core thermionic and other generating systems.

d. The technology advancement requires improved-component selection, evaluation, integration and demonstration. To accomplish this, performance and life-testing of final integrated cylindric thermionic-converter, heat-pipe modules is desirable.

TO BE CARRIED TO LEVEL 10

DEFINITION OF TECHNOLOGY REQUIREMENT	NO.

1. TECHNOLOGY REQUIREMENT(TITLE): High-Performance Thermionic Conversion

7. TECHNOLOGY OPTIONS:

During the present rtt stage running through late 1970's, technology options will be indicated.

8. TECHNICAL PROBLEMS:

The technical problems involved in thermionic-conversion R & T, are selection, demonstration, and integration of improved emitters, collectors, and plasma-loss-reduction devices.

9. POTENTIAL ALTERNATIVES:

No competive high-temperature, low-pressure static thermal-energy converter is available.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

RTOP 506-24-21

EXPECTED UNPERTURBED LEVEL

11. RELATED TECHNOLOGY REQUIREMENTS:

a. Materials selection and evaluation
b. Liquid-metal heat-pipe development

DEFINITION OF TECHNOLOGY REQUIREMENT NO.

1. TECHNOLOGY REQUIREMENT (TITLE): High-Performance Thermionic Conversion

PAGE 3 OF ___.

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Select, screen, test converter components	—	—	—	—	—														
2. Determine & specify electrode processing				—	—	—													
3. Verify 30% efficiencies,				—	—	—													
4. extrapolate 10-year lives																			
5.																			
APPLICATION																			
1. Design (Ph. C)			—	—	—	—	—												
2. Devl/Fab (Ph. D)						—	—	—	—	—	—	—	—	—					
3. Operations													—	—	—	—			
4. >100We missions															—	—	—	—	—

13. USAGE SCHEDULE:

	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	TOTAL
TECHNOLOGY NEED DATE						Δ												
NUMBER OF LAUNCHES																		

14. REFERENCES:

NASA, ERDA Thermionic-Conversion Program Reviews
RTOP's 506-24-21, 506-16,31
Outlook for Space
Future Payload Technology Requirements Study

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. ______

1. TECHNOLOGY REQUIREMENT (TITLE): Solar Dielectric Power Conversion PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Electric Power

3. OBJECTIVE/ADVANCEMENT REQUIRED: Conversion of solar energy to electricity at a mass of 10 kg/kw.

4. CURRENT STATE OF ART: 50-100 kg/kw

HAS BEEN CARRIED TO LEVEL 7

5. DESCRIPTION OF TECHNOLOGY

The use of a thin film of dielectric material with electrically conducting cover layers is bonded to the surface of the spacecraft. The device operates by alternate heating and cooling of the dielectric (rotating spacecraft).

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☒ C/D

6. RATIONALE AND ANALYSIS:

Forecasts of the kg/we for this device range from 2.0×10^{-5} for the 1975-1985 period to 1.0×10^{-5} for 2000.

The propulsion working group submitted a requirement for a flight qualified system with appropriate power conditioning for electric propulsion loads.

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT | NO.

1. **TECHNOLOGY REQUIREMENT(TITLE):** Solar Dielectric Power Conversion | **PAGE 2 OF 3**

7. **TECHNOLOGY OPTIONS:**

Ambient field trapping; solar photovoltaic, solar thermionic, Mass per unit power ratios of 10-100 kg/kw or kg/we ratios of 1-7×10^{-2} (1975-85) or 7×10^{-3}--3×10^{-2} (2000).

8. **TECHNICAL PROBLEMS:**

Requirement for alternate heating and cooling:
Suitable Dielectric materials
Bonding materials cover layer material

9. **POTENTIAL ALTERNATIVES:**

Solar PV	MGD
Field Trapping	RTIG
Solar Thermionic	MGD

10. **PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:**

unknown

EXPECTED UNPERTURBED LEVEL 3

11. **RELATED TECHNOLOGY REQUIREMENTS:**

unknown

DEFINITION OF TECHNOLOGY REQUIREMENT NO.

1. TECHNOLOGY REQUIREMENT (TITLE): Solar Dielectric Power Conversion PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Analysis																			
2. Design																			
3. Test																			
4. Flight						*													
5. Anal. of Acc.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4. Flight Qual.							*												

13. USAGE SCHEDULE:

	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	TOTAL
TECHNOLOGY NEED DATE								*										
NUMBER OF LAUNCHES						1	1	3	2	3	3	4	4	4	4			33

14. REFERENCES:

1. "Report of the Outlook for Space Study," July 1975.
2. "A Forecast of Space Technology," Vol. II., July 1975.

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. ______

1. TECHNOLOGY REQUIREMENT (TITLE): Nuclear Thermoelectric Power Systems PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Electric Power

3. OBJECTIVE/ADVANCEMENT REQUIRED: Increase the efficiency by a factor of two (up to 14%), increased life, possible use as an alternative to RTGs at power levels of 500-2500 We.

4. CURRENT STATE OF ART: Silicon-germanium, telluride units with efficiencies up to 5%.

HAS BEEN CARRIED TO LEVEL 7

5. DESCRIPTION OF TECHNOLOGY

Thermoelectric conversion, because of the present low efficiency (5%) is limited to relatively low power (100-1500We) applications which are required for very long periods of time (RTGs). The most pressing needs are (1) to determine the interference problems with scientific instruments when the RTG is integrated into the spacecraft; (2) to perform theoretical and experimental studies to determine the potential capability of this system; (3) to identify candidate thermoelectric materials which should be developed by ERDA for application to NASA missions and (4) identify new thermoelectric conversion materials which can significantly improve RTG performance.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☒ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

RTGs are an established, space tested (model), power source for mars lander and outer planet missions. Long range planning documents indicate a continuing need for RTGs. A review of the 1973 mission Model indicates at least 15 flight isotope power systems of varying performance and power levels are needed through the 1980's.

The high cost of using actual RTGs in instrument and other integration studies clearly indicates the need for a program which will characterize the RTG and produce simulators which may be used in screening, development and integration testing. Both Pu-238 and Cm-244 fuels should be assumed. A future generation of thermoelectric conversion systems for use in space will require reactor power sources. Work should be undertaken to characterize conversion materials and devices to be used with reactors.

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT NO.

1. **TECHNOLOGY REQUIREMENT(TITLE):** Nuclear Thermoelectric Power Systems **PAGE 2 OF 3**

7. **TECHNOLOGY OPTIONS:**

The present tellurides are suitable for hot junction temperatures of 800-950°K and produce efficiencies of 4.5-6%.
The Si-Ge units operate from 1150 to 1250°K and produce efficiencies of 4-6%.

8. **TECHNICAL PROBLEMS:**

Degradation of high performance selenide materials.
Shielding requirements for Cm-244.

9. **POTENTIAL ALTERNATIVES:**

Use of dynamic conversion cycles or thermionics.

10. **PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:**

RTOP 506-24-41 Nuclear Thermoelectric Systems Technology
Plasma Core Reactor Research

EXPECTED UNPERTURBED LEVEL 5

11. **RELATED TECHNOLOGY REQUIREMENTS:**

DEFINITION OF TECHNOLOGY REQUIREMENT NO.

1. TECHNOLOGY REQUIREMENT (TITLE): Nuclear Thermoelectric Power Systems PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Analysis/Design																			
2. Fabrication																			
3. Ground Test																			
4. Flight Design/Fab.																			
5. Space Demonstration					*														
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																	TOTAL
TECHNOLOGY NEED DATE				*													
NUMBER OF LAUNCHES																	

14. REFERENCES:

Input data Pkg. to Power Working Group "Outlook for Space Reference Volume"
A Forecast of Space Technology
RTAC Aa Hoc Working Group Report 7 May, 1975.

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

I. Energy Sources and Conversion

C. Chemical Conversion Systems

Two technology requirements are proposed for Chemical Conversion Systems. They are:

1. Dielectric Film Stack Cryogenic Tank Insulation

2. Fuel Cell Technology Advancement

Improved insulation systems are required for future missions where cryogens must be stored for long periods of time. The use of radiation shields which selectively reflect certain wavelengths of heat energy potentially offer an order of magnitude reduction in heat leak to spacecraft cryogenic tankage.

A large photovoltaic space station power system will require a large energy storage system to provide dark side power. A regenerative fuel cell system consisting of a fuel cell in conjunction with an electrolysis cell offers significant weight savings relative to conventional secondary battery systems. A development program to match fuel cells with electrolysis cells having 5000 hour life is required.

Other fuel cell technology advancements include development of cheap, stable catalysts, ion-exchange membrane fuel cells which offer life, weight and cost advantages and "Nafion" hollow fiber fuel cells which offer size and weight reductions.

All chemical conversion technology is considered as opportunity driven.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. ____

1. TECHNOLOGY REQUIREMENT (TITLE): Dielectric Film Stack Cryogenic Tank Insulation PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Electric Power

3. OBJECTIVE/ADVANCEMENT REQUIRED: Reduce recent theory to practice by design and fabrication of a high performance insulating material which shields over the 1-100 micrometer spectral range.

4. CURRENT STATE OF ART: Current heat leaks to stored cryogens range from .03 to .5 BTU/HR FT^2 of surface area.

HAS BEEN CARRIED TO LEVEL __

5. DESCRIPTION OF TECHNOLOGY

Low boil-off containers for cryogenic fluids are vacuum jacketed dewars. Attention is given to minimizing heat paths across supports and radiation through the vacuum jacket. Multiple layers of flexible metalized films (Au, Ag, or AL) are used in the annulus for the purpose as are powders and glass beads or micro spheres.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS.

Mission durations of 6 months to several years are desirable in earth orbit and are required for deep space exploration. Vastly improved cryogenic insulation will greatly reduce boil-off. For example a 225 ft. vessel would on a one year mission, boil-off 50 to 70 lbs of H_2 with a spectral film stack insulation, whereas a conventional dewar would boil-off 500-700 lbs. Based on shuttle costing rationale ($50k/lb) a 600 lb saving represents approximately $30m. This technology can be used on the tug.

TO BE CARRIED TO LEVEL __

DEFINITION OF TECHNOLOGY REQUIREMENT NO.

1. TECHNOLOGY REQUIREMENT(TITLE): Dielectric Film Stack Cryogenic Tank Insulation (Elec. Power) PAGE 2 OF 3

7. TECHNOLOGY OPTIONS:

Develops in-flight refrigeration or liquifaction systems which would be heavy and expensive.

8. TECHNICAL PROBLEMS:

A film stack design is needed which will provide a high reflectance over a wider band of the spectrum than is now available. Also a MFG problem of thickness control on 3 ft. wide rolls needs to be solved.

9. POTENTIAL ALTERNATIVES:

Continue to try to improve existing insulation schemes; however, the potential is limited.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

EXPECTED UNPERTURBED LEVEL __

11. RELATED TECHNOLOGY REQUIREMENTS:

DEFINITION OF TECHNOLOGY REQUIREMENT NO.

1. TECHNOLOGY REQUIREMENT (TITLE): Dielectric Film Stack Cryogenic Tank Insulation PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Analysis																			
2. DES, FAB & Test 2-10 layer samples																			
3. FAB & Test 20-40 layer samples																			
4. Qualify																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																	TOTAL
TECHNOLOGY NEED DATE																	
NUMBER OF LAUNCHES																	

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT — NO. ______

1. TECHNOLOGY REQUIREMENT (TITLE): Advanced Fuel Cell Technology — PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Electric Power

3. OBJECTIVE/ADVANCEMENT REQUIRED: Investigate several possible advancements in fuel cell technology to increase efficiency, life, and decrease cost.

4. CURRENT STATE OF ART: Current fuel cells have expensive and short lived catalysts. They require technology advancements to extend life and decrease weight.

HAS BEEN CARRIED TO LEVEL __

5. DESCRIPTION OF TECHNOLOGY

1. Today's fuel cells use noble metal catalysts for acceptable system operation. In order to attain long lifetimes the system temperature must be kept low (300°F). New catalysts must be found which are inexpensive and stable over long operating lifetimes.
2. Fuel cells are being developed for Shuttle. Electrolysis units are being developed for life support systems. These concepts need to be combined in a regenerative fuel cell system program.
3. New concepts for fuel cells which offer potential advantages in performance, life and weight have been brought to various stages of R & D. Further development is required.
4. The ion-exchange membrane concept developed by GE has shown by test that performance is invariant over 35,000 hours of operation. The potential exists for a 100,000 hour system.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

1. Significant cost savings can be realized in fuel cell systems if a cheap stable catalyst can be found for low temperature fuel cells.

2. For advanced applications such as solar arrays on space stations [illegible]re large power storage is required for the dark side operation, a reg[illegible]erative fuel cell offers an attractive weight advantage over secondary batteries.

3. Where requirements may dictate an extremely long life fuel cell, no degradation, and one w[illegible]ich is capable of usine propulsion grade reactants the ion-exchange membrane (IEM) concept is very attractive.

TO BE CARRIED TO LEVEL __

DEFINITION OF TECHNOLOGY REQUIREMENT NO.

1. **TECHNOLOGY REQUIREMENT(TITLE):** Advanced Fuel Cells Technology PAGE 2 OF 3

7. **TECHNOLOGY OPTIONS:**

The options which exist today are confined to hydrogen/oxygen fuel cells for space applications.

8. **TECHNICAL PROBLEMS:**

1. Noble metal catalysts are too costly and tend to be poisoned easily.
2. Work in system optimization needs to be done in regenerative fuel cell systems.
3. Further research in new concepts such as the hollow fibre fuel cell should be directed toward lowering IR losses, and finding ways to control temperature.
4. The IEM concept needs system optimization.

9. **POTENTIAL ALTERNATIVES:**

None.

10. **PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:**

1. A low level effort is underway to develop single cells and small stacks of the IEM Concept.
2. The hollow fibre concept has been investigated in the laboratory at JPL.

EXPECTED UNPERTURBED LEVEL __

11. **RELATED TECHNOLOGY REQUIREMENTS:**

I. Energy Sources and Conversion

A. Ambient Field Trapping

No experiments were identified.

II. Power Processing, Distribution, Conversion and Transmission

A series of technology advancements are required in the power processing, distribution, conversion and transmission area to support future mission requirements. While an exact set of missions cannot be delineated which require the technology requirements described herein, there exists a general class of high energy, high voltage, long life missions that would benefit immeasureably from these technology advances. In fact, several missions included in this classification would not be feasible with existing technology, or that forecast for availability within the required time periods without a significant effort by NASA.

A high voltage (100V-15KV) distribtion system will be required for satellites employing advanced communication travelling wave tubes and ion propulsion. If a reliable high voltage distribution is not available, severe weight, power loss and thermal dissipation penalties must be paid where present low voltage distribution systems are employed. A series of suggested technology requirements are outlined to permit development of a high voltage/ power system. Further advancements will be required for the SSPS, space station and colonization class of power systems (gigawatt power processing and distribution systems) with corresponding increases in reliable operational lifetime (up to 10 years).

Development of the SSPS system will result in the requirement for a highly efficient/reliable means of satellite-to-ground transmission and reconversion system. For laser energy transmission to become attractive for SSPS-type application, substantial improvements in on-the-ground reconversion efficiency must be accomplished. A suggested program for development of a highly efficient GaAs Schottky Barrier Diode laser energy photovoltaic converter is discussed. Microwave transmission of energy remains a potentially viable alternative, although no specific programs are outlined.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. ____

1. TECHNOLOGY REQUIREMENT (TITLE): Power Processing and Distribution Systems for Gigawatt Class Power Systems PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Electric Power

3. OBJECTIVE/ADVANCEMENT REQUIRED: Advance the technology to permit processing and distribution of gigawatt class power system.

4. CURRENT STATE OF ART: Most power systems currently being flown are in the few hundred watt class. Up to 50kw systems are in early development phases and are being discussed for NEP. HAS BEEN CARRIED TO LEVEL __

5. DESCRIPTION OF TECHNOLOGY

An ultra large class of power systems will be required for SSPS, space station, or colonization attempts now under discussion. The technology to provide perhaps 5 gigawatts of processing and distribution must be approached through various plateaus of power levels; 5 kw is in hand, 50 kw and 500 kw are proposed technology. Intermediate steps between 500 kw and 5 gigawatts must be reached.

A variety of power sources must be accomodated as well as several types of loads. The need for 30 year life times and the resultant testing and confidence building programs place a significantly different emphasis on the technology.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. SSPS studies have identified needs in the gigawatt class.
b. SSPS, space station, colonization would all benefit from this technology advancement.
c. These advancements in power processing and distribution are mandatory to the accomplishment of the above stated missions.
d. This technology must eventually grow to flight status if the gigawatt class power systems are to become reality.

TO BE CARRIED TO LEVEL __

DEFINITION OF TECHNOLOGY REQUIREMENT NO.

1. TECHNOLOGY REQUIREMENT(TITLE): Power Processing and Distribution Systems for Gigawatt Class Power Systems

7. TECHNOLOGY OPTIONS:

Options and possible approaches must be identified and an approach structured. The options are systematic, that is, they must interrelate with the source (solar, nuclear or other), the load, transportation and assembly techniques, maintenance requirements and accessability.

8. TECHNICAL PROBLEMS:

Concept, approach, source and load definition, materials, long life testing techniques, weight, efficiency, thermal control.

9. POTENTIAL ALTERNATIVES:

None if the proposed uses are to materialize.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Existing work on RTOP 506-23-3 is barely embryonic.

EXPECTED UNPERTURBED LEVEL __

11. RELATED TECHNOLOGY REQUIREMENTS:

Many

DEFINITION OF TECHNOLOGY REQUIREMENT	NO.

1. TECHNOLOGY REQUIREMENT (TITLE): Power Processing and Distribution Systems for Gigawatt Class Power Systems

PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1.																			
2.																			
3.																			
4.																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																	TOTAL
TECHNOLOGY NEED DATE																	
NUMBER OF LAUNCHES																	

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. ______

1. TECHNOLOGY REQUIREMENT (TITLE): Higher Bus Voltage Power Processor and Distribution System Technology PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Electric Power

3. OBJECTIVE/ADVANCEMENT REQUIRED: Develop the technology to permit use and eventual standardization of a higher bus voltage for housekeeping and general purpose space missions.

4. CURRENT STATE OF ART: 28 VDC/110VAC are routinely used on spacecraft; 76VDC is being used on CTS.

HAS BEEN CARRIED TO LEVEL __

5. DESCRIPTION OF TECHNOLOGY

A suitable busline voltage in excess of 100VDC, and perhaps an AC voltage higher than 110, should be established. The various technologies should be pursued and demonstrated to permit use of these increased line voltages. Specifically intended are:

- --Power processors, complete with controls, regulation, etc., at increased power levels
- --Distribution systems, including remotely controlled switches, sensors, conductors, substations, connectors
- --Long life, high efficiency, low weight and low cost goals
- --Systems consideration, EMI, noise, compatability.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. At power levels above several hundred watts the copper weights, power losses and thermal dissipations impose increasing penalties. These penalties can be significantly reduced at higher (greater than 100 VDC) voltages instead of the traditional 28 VDC.

b. Shuttle could have benefited significantly by using a higher bus voltage; any future payload or vehicle requiring greater than several hundred watts can achieve a savings.

c. Improvements can be significant in weight reductions, electrical efficiencies, and thermal losses.

d. Ground based tests are suitable for all aspects of technology development. A space demonstration flight may be necessary for user confidence.

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT **NO.**

1. **TECHNOLOGY REQUIREMENT(TITLE):** Higher Bus Voltage Power Processor and Distribution System Technology

7. **TECHNOLOGY OPTIONS:**

Current low voltage bus systems can continue to be used for some time with the attendant penalties. However, at some power levels these penalties can become prohibitive.

8. **TECHNICAL PROBLEMS:**

High voltage, high power switching devices and distribution components, long life time materials at elevated voltages, plasma current interactions.

9. **POTENTIAL ALTERNATIVES:**

None.

10. **PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:**

RTOP 506-23-3 currently applies

EXPECTED UNPERTURBED LEVEL ___

11. **RELATED TECHNOLOGY REQUIREMENTS:**

DEFINITION OF TECHNOLOGY REQUIREMENT NO.

1. TECHNOLOGY REQUIREMENT (TITLE): Higher Bus Voltage Power Processor and Distribution System Technology

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Analysis	---	---																	
2. Design		---	---																
3.																			
4.																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																		TOTAL
TECHNOLOGY NEED DATE																		
NUMBER OF LAUNCHES																		

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. ______

1. TECHNOLOGY REQUIREMENT (TITLE): Laser Energy Photovoltaic Converter PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Electric Power

3. OBJECTIVE/ADVANCEMENT REQUIRED: Laser Energy Photovoltaic Converter with 80% efficiency.

4. CURRENT STATE OF ART: Silicon Laser Energy Converters are at least 15% efficient.

HAS BEEN CARRIED TO LEVEL 4

5. DESCRIPTION OF TECHNOLOGY

Match the energy band-gap of $GaAs_{1-x}P_x$ Schottky Barrier diodes to the photon energy of the laser to obtain maximum efficiencies. Preliminary efforts have resulted in efficiencies up to 30%.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. High efficiency power transmission and conversion must be obtained if the SSPS is ever to be feasible.
b. SSPS
c. Higher efficiency, lower cost, smaller size of SSPS.
d. Level 5.

TO BE CARRIED TO LEVEL 5

DEFINITION OF TECHNOLOGY REQUIREMENT NO.

1. TECHNOLOGY REQUIREMENT(TITLE): Laser Energy Photovoltaic Converter

7. TECHNOLOGY OPTIONS:

Decreased Laser Conversion Efficiency with increased cost and size of SSPS.

8. TECHNICAL PROBLEMS:

a. Increasing open circuit voltage of diode.
b. Possible material problems (contacts, A/R coating, etc.) for high energy density operation.

9. POTENTIAL ALTERNATIVES:

Microwave transmission and detector.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

RTOP 506-25-52

EXPECTED UNPERTURBED LEVEL

11. RELATED TECHNOLOGY REQUIREMENTS:

High efficiency GaAap "AMOS" solar cell.

DEFINITION OF TECHNOLOGY REQUIREMENT	NO.

1. TECHNOLOGY REQUIREMENT (TITLE): Laser Energy Photovoltaic Converter — PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1.																			
2.																			
3.																			
4.																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

TECHNOLOGY NEED DATE																	TOTAL
NUMBER OF LAUNCHES																	

14. REFERENCES:

"Photo-Voltaic Conversion of Laser Energy," by R. J. Stirn, in Proceedings of Second Laser Energy Conversion Conference, at NASA-Amer. Research Center, January, 1975.

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. ______

1 TECHNOLOGY REQUIREMENT (TITLE): Ultra High Power Energy Conversion and Transmission System Technology PAGE 1 OF 2

2. TECHNOLOGY CATEGORY: Electric Power

3. OBJECTIVE/ADVANCEMENT REQUIRED: Provide the technology to permit conversion, transmission, reception and reconversion from space to planet of power levels in the gig att class.

4. CURRENT STATE OF ART: Microwave transmission of a few hundred watts near 50% efficiency is being accomplished on CTS; laser transmissions of 1% efficiency for 1000 km distances can be accomplished.

HAS BEEN CARRIED TO LEVEL __

5. DESCRIPTION OF TECHNOLOGY

Radical advances in efficiences and power levels must be achieved in the areas of conversion, transmission, reception and reconversion of gigawatt class power levels. Both laser and microwave approaches have been proposed and are in various stage of technology. An aggresive and well organized technology attack should be conducted to exploit the potential of these two approaches.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. The gigawatt class of power levels has been identified by SSPS conceptual studies.
b. Colonization attempts could be solely dependent upon this technology, as is SSPS.

TO BE CARRIED TO LEVEL __

DEFINITION OF TECHNOLOGY REQUIREMENT NO.

1 TECHNOLOGY REQUIREMENT(TITLE): Ultra High Power Energy Conversion and Transmission System Technology

7. TECHNOLOGY OPTIONS:

Microwaves and lasers both offer potential advantages and each has its own disadvantages. Both need continued exploitation and development (perhaps also research) to fully evaluate their ultimate capabilities and limitations.

8. TECHNICAL PROBLEMS:

Numerous.

9. POTENTIAL ALTERNATIVES:

1. Do not strive for SSPS capability.
2. Consider other schemes for powering a space colony.
3. Identify and exploit alternate transmission concepts.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

EXPECTED UNPERTURBED LEVEL __

11. RELATED TECHNOLOGY REQUIREMENTS:

III. Storage

Past Phase "B" studies of the 8 to 10-man space station have indicated a requirement for a high capacity NiCd battery system of approximately 100 amp. hrs. The requirements for development are determined by the Technology Requirement Form. An alternate battery approach to solving this problem is the use of a metal-gas battery system. There is a proposal for the development for a smaller battery of this type in The Mission Driver Section of this report. The technology defined under that proposal will also apply to this application.

Anothe energy storage system with potential for high energy density is the use of flywheels for mechanical storage. This will be particularly true if the development programs for high strength fiber composites and new concepts in fabrication of these devices are successful. Details of this technology proposal are available from the Technology Development Form.

The Regenerative Fuel Cell is also considered an improvement over batteries for electrical energy storage for high energy systems. A proposed technical program for that system is included under Chemical Conversion in this report and the same technology will apply for this application.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. ______

1. TECHNOLOGY REQUIREMENT (TITLE): Large Ni-Cd Batteries for Space Station Application PAGE 1 OF 4

2. TECHNOLOGY CATEGORY: Electric Power (17)

3. OBJECTIVE/ADVANCEMENT REQUIRED: Development and demonstration of high capacity, long life NiCd battery systems.

4. CURRENT STATE OF ART: Smaller NiCd batteries have been extensively used in spacecraft.

HAS BEEN CARRIED TO LEVEL 5

5. DESCRIPTION OF TECHNOLOGY

Past studies of the 8 to 10 man space stations indicated a requirement for a 100 Amplir. NiCd battery system. Prototype cells have been built and preliminary thermal packaging concepts have been analyzed. There are several factors that presently limit the operational capabilities of NiCd. batteries and therefore affect the supporting subsystems. These limitations include capacity degradation at useable voltage levels, operating temperatures, charge and discharge rates, and depths of discharge. These operating limits will be more restrictive in large cell application.

Improved technology is required to support the requirements of long life, maintainability, etc.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☒ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. Past Phase B studies on the initial space station resulted in a recommendation for a solar array source with a NiCd battery for energy storage.
b. The space station requires higher performance and longer life than previously demonstrated by NiCd batteries in addition to module maintainability.
c. The high capacity batteries should demonstrate a capability to provide a two year life time while operation at an acceptable of performance by laboratory test program.

TO BE CARRIED TO LEVEL 8

DEFINITION OF TECHNOLOGY REQUIREMENT — NO.

1. **TECHNOLOGY REQUIREMENT(TITLE):** Large NiCd Batteries for Space Station Application — PAGE 2 OF 4

7. TECHNOLOGY OPTIONS:

Probably the characteristic of NiCd batteries that has the biggest impact on operational performance is the degradation of the useable capacity. This is particularly true for operation above 20°C. Obviously one approach to minimize this effect is to maintain the batteries at a lower temperature (10°C). This obviously impacts the vehicle thermal control system. Another option is to provide on-board reconditioning capability. Some improvement in materials and manufacturing of electrodes, separators and electrolyte will also improve capabilities. In all probability, all options open for improvement of NiCd battery operations will be required to support the space station requirements.

8. TECHNICAL PROBLEMS:

Techniques for maintaining lower temperatures and inflight reconditioning are known but must be developed. The changes in electrode characteristics during cycling is not completely understood. The first step in improving this operation is to acquire an understanding of this basic problem. This will probably require an extensive test program.

9. POTENTIAL ALTERNATIVES:

Other methods of providing the required energy storage system include the development of a regenerative or secondary fuel cell system or metal-gas electrode battery systems.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

There are no other programs requiring the large NiCd cell however any improvement in basic NiCd battery technology will benefit this requirement.

EXPECTED UNPERTURBED LEVEL 5

11. RELATED TECHNOLOGY REQUIREMENTS:

Thermal Control System will be impacted but no technology problem anticipated.

DEFINITION OF TECHNOLOGY REQUIREMENT NO.

1. TECHNOLOGY REQUIREMENT (TITLE): Large NiCd Batteries for Space Station Application PAGE 3 OF 4

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM*	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Electrode & separate or evaluation Testing		---	---	---															
2. Cell component analysis		---	---	---	---														
3. Battery packaging and thermal control			---	---	---	---													
4. In-flight reconditions evaluation and development			---	---	---	---													
5.																			
*Schedule start will depend on available funding and future planning.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE: Opportunity Driven

																	TOTAL
TECHNOLOGY NEED DATE																	
NUMBER OF LAUNCHES																	

14. REFERENCES:

1975 NASA OAST Summer Workshop Overview Report - Developing Space Occupancy: Perspectives on NASA Future Space Program Planning.

Funding:	CY	
	76	$250k
	77	150
	78	150
	79	100
	80	50

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT

NO. ______

1. TECHNOLOGY REQUIREMENT (TITLE): Use of Flywheels for Mechanical Storage of Energy

2. TECHNOLOGY CATEGORY: Electric Power

3. OBJECTIVE/ADVANCEMENT REQUIRED: Flywheels promise a high ratio of energy stored per unit mass.

4. CURRENT STATE OF ART: Various materials and designs for the flywheel have been evaluated. Some demonstrations performed.

HAS BEEN CARRIED TO LEVEL 4

5. DESCRIPTION OF TECHNOLOGY

The use of flywheels for energy storage has been considered for space applications because of their potential superiority over chemical batteries in terms of energy stored per unit mass. Upon the development of high-strength fiber composites and implementation of new concepts in fabrication these devices can become effective elements for long-term energy storage.

Assuming the use of magnetic bearings and electro-mechanical energy storage coupling techniques, lifetimes of 30 years or more should be achieveable. The availability of the vacuum environment permits long standby life and very small required auxiliary equipment mass. No significant work has been done on the integration of the complex flywheel system which will probably require as much effort as the technology of the flywheel itself.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☒ C/D

6. RATIONALE AND ANALYSIS:

Widely variable rates of power can be utilized, both in charging and discharginig, with essentially constant (and high) efficiency; providing the transmission or electrical controls are developed.

Flywheel materials which have been studied in recent years include high strength steels, titanium and fiber composites. Beacuse of the high strength of fibers flywheels with very high energy storage per unit mass are possible. For example the theoretical limit for fused silica fibers is 870 W-H/kg compared to 48W-H/kg for a ferrous metal base flywheel. Design values for stress for composite flywheels are lacking, the evolution of new fabrication techniques, the overall system integration analysis, and the development of suitable bearings, seals, transmissions, and electrical controls are driving the technology.

The propulsion group has recommended an evaluation of flywheels for use with electric propulsion systems.

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT NO.

1. **TECHNOLOGY REQUIREMENT(TITLE):** Use of Flywheels for Mechanical Storage of Energy

7. **TECHNOLOGY OPTIONS:**

	kg/J	$/kg
Flywheels	$1\text{-}1.5 \times 10^{-6}$	$1\text{-}4 \times 10^{1}$
Superconductors	$2\text{-}6 \times 10^{-5}$	$2\text{-}3 \times 10^{2}$
Primary Batteries	$2 \times 10^{-6}\text{-}4 \times 10^{-7}$	$1\text{-}5 \times 10^{2}$
Secondary Batteries	$3\text{-}8 \times 10^{-6}$	$1\text{-}4 \times 10^{3}$
Stable Chemicals	$1\text{-}8 \times 10^{-8}$	$4 \times 10^{1}\text{-}2 \times 10^{2}$

8. **TECHNICAL PROBLEMS:**

Containment housings for failures--minimized for composites due to high fracture energy.

Vacuum bearings thansmission.

Uncertainties in design stress values.

9. **POTENTIAL ALTERNATIVES:**

Batteries

10. **PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:**

Low level, research efforts on composite fiber flywheels

RTOP 909-74-35 LaRC
506-19-13 LaRC

EXPECTED UNPERTURBED LEVEL 5

11. **RELATED TECHNOLOGY REQUIREMENTS:**

DEFINITION OF TECHNOLOGY REQUIREMENT NO.

1. TECHNOLOGY REQUIREMENT (TITLE): Use of Flywheels for Mechanical Storage of Energy

PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Analysis	—	—																	
2. Design		—	—																
3. Fabrication		—	—																
4. Test			—	—															
5. Flight Test						Δ													
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	TOTAL
TECHNOLOGY NEED DATE								Δ										
NUMBER OF LAUNCHES																		

14. REFERENCES:

Ad Hoc Working Group on Space Power and Propulsion--RTAC May, 1975.

Outlook for Space-Forecast of Space Technology-Part IV Management of Energy

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

CONCLUSIONS

The conclusions reached by the PWG are as follows:

1. Power systems technology currently available or in work is adequate to accomplish all missions in the 1973 Mission Model. The few exceptions to this generalization represent only modest extensions of ongoing efforts.

2. Improved Power Systems technology can provide significant benefits in operational capabilities and costs, even for the 1973 Mission Model. Sixteen such areas have been identified.

3. Major advancements in Power Systems technology must be made if, and only if, the Outlook for Space and other advanced user plans are to be accomplished. Most of these advancements are not now actively in work. Nineteen such areas have been identified.

4. A vigorous space experiment program is needed to achieve these accomplishments. Specifically, 23 space experiments have been identified.

APPENDIX A

INPUTS TO THE POWER WORKING GROUP

Ideas brought from the various centers by PWG members.

Inputs from other Summer Workshop working groups.

"Selected Technology Suggestions for Future Space Application and Related Space Experiments." Aerospace Corporation Presentation to OAST Workshop. (August 6, 1975)

"Ad Hoc Working Group on Space Power and Propulsion - Report On The Status and Prospects of the NASA Space Power and Propulsion Research and Technology Program." Vol. 1. (April 30, 1975)

"Outlook Outputs" J. D. Burke. Presentation on 249 Missions, plus Synopses of each. (July 1975)

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The 1973 NASA Payload Model -- Space Opportunities 1973-1991 NASA (June 1973)

Missions (Vol. 2) Draft copy of Illustrative Mission (F. T. Lomes) plus 75 mission

"Gaseous Fuel Nuclear Reactor Research" F. C. Schwenk and K. Thom. NASA (October 1974) Presented to the Oklahcma State University. Frontiers of Power Technology

"Presentation of the Power Working Group to the Space Transportation Systems Technology Steering Committee." D. T. Bernatowicz (January 2? 1974)

"Presentation of the Power Working Group to the Space Transportation Systems Technology Steering Committee." D. T. Bernatowicz (October 25, 1973)

"AFSC-NASA Space Technology Meeting Briefing Charts for the Space Power Program." J. D. Reams (AF/Aero Propulsion Lab)

"International Astronautical Federation XXV Congress." J. P. Layton (October 3, 1974) Space Power Systems: Retrospect and Prospect

"Aerospace Technology Development of Three Types of Solid State Remote Power Controlled for 110V DC with current ratings of five and thirty amperes, One type having current limiting." D. E. Baker NASA CR-134772 (WAED 75-01E). (February 1975)

"Ad Hoc Working Group on Space Power and Propulsion -- Report on the Status and Prospects of the NASA Space Power and Propulsion Research and Technology Program." Vol. I & II. NASA/R & D Advisory Council (May 7, 1975) (RTAC)

Future Payload Technology Requirement Study, Final Report (June 1975) General Dynamic, Convair Division (CASD-NAS-75-004, Constract NAS 2-8272).

Outlook for Space, A Forecast of Space Technology (1980-2000) (July 15, 1975) Final Draft.

1975 NASA OAST Summer Workshop - Overview Report

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"Input Data Package for Power Working Group" (Complete) S. Tiwari

"Automated Power Systems Management" (RTOP 506-23-34) JPL H. Wainel (June 10, 1975)

"Long Duration Exposure Facility." Presentation to OAST Space Technology Workshop (August 5, 1975) R. L. Osborne

Payloads Technology Space Testing Needs, Preliminary Briefing (August 5, 1975) General Dynamics, Convair Division. Report No. FT-WP-002

"Space Experiment Opportunities to Support the Outlook for Space Technology Recommendations" (August 4, 1975) Presentation to OAST Workshop. R. L. Chase/JPL

"OAST Planning and Supporting Studies" (August 4, 1975) Presentation to OAST Workshop. S. R. Sadin NASA/OAST-RX

Space Shuttle System Payload Accommodations (July 3, 1974) Vol XIV, Johnson Space Center Report No. 07700 (Rev C)

Space Experiment Opportunities to Support the Outlook for Space. Technology Recommendation (July 1975) Jet Propulsion Laboratory

Outlook for Space. Executive Summary (July 1975) NASA, Internal Review Draft

Shuttle/Spacelab Reference Document (July 1975) R. H. Smith, A. N. Williams, Jet Propulsion Laboratory

"Office of Space Science: Statement of New Technology Requirements Prepared for the OAST Workshop -- August 3-16, 1975"

Future Payload Technology Space Testing and Development Requirements (Preliminary) General Dynamics/Convair Division (August 5, 1975) Report No. FT-WP-001, Contract NAS2-9815

Spacelab: Payload Accommodation Handbook (May 1975) (Preliminary) ESRO/ESTEC Ref. No. SLP/2104.

Space Research & Technology Study (Draft Copy). (August 1972) NASA Headquarters

APPENDIX B

Detailed Outline

I. Energy Sources and Convertors

- A. Solar Photovoltaic
  1. HVS
  2. Solar Concentrators
  3. Plasma Interactions with HV Surfaces
  4. Large Scale Array
  5. Array Deployment and Dynamics
  6. Qualification of Cells
  7. Achieving High Efficiency
  8. Shuttle Calibration Facility
  9. Tethered Array
  10. Power Transfer
  11. Advanced Concepts
      - a. EWECS
- B. Solar and Nuclear Thermal Electric
  1. Solar Concentrators
  2. Brayton Cycle
  3. Rankine Cycle
  4. Stirling Cycle
  5. Thermionic
  6. Thermoelectric
  7. Dielectric
  8. MHP
  9. RTGS
  10. Reactors

C. Chemical Conversion

1. Dynamic Conversion

2. Primary Fuel Cells

3. Primary Batteries

D. Ambient Field Trapping

II. Power Processing, Distribution, Conversion and Transmission

A. Processing

B. Conversion

Laser Photovoltaic

C. Distribution

D. Transmission

1. Microwave

2. Laser

III. Storage

A. Mechanical

B. Thermal

C. Chemical

Regenerative Fuel Cells

D. Electrochemical